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U.S. ECONOMIC GROWTH FROM 1976 TO 1986: PROSPECTS, PROBLEMS, AND PATTERNS

Volume 9—Technological Change

STUDIES

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LETTERS OF TRANSMITTAL

December 28, 1976.

To the Members of the Joint Economic Committee:

Transmitted herewith is the ninth volume of the Joint Economic Committee study series entitled "U.S. Economic Growth From 1976 to 1986: Prospects, Problems, and Patterns." This series of over 40 studies forms an important part of the Joint Economic Committee's 30th anniversary study series, which was undertaken to provide insight to the Members of Congress and to the public at large on the important subject of full employment and economic growth. The Employment Act of 1946, which established the Joint Economic Committee, requires that the committee make reports and recommendations to the Congress on the subject of maximizing employment, production and purchasing power.

Volume 9 comprises two studies which examine the ways in which technological change will influence future economic growth rates and patterns. The studies were done by Prof. Nathan Rosenberg and by Dr. Joseph Coates. The committee is indebted to these authors for their fine contributions which we hope will serve to stimulate interest and discussion among economists, policymakers and the general public, and thereby to improvement in public policy formulation.

The views expressed are those of the authors and do not necessarily represent the views of the committee members or committee staff.

Sincerely,

Hubert H. Humphrey,
Chairman, Joint Economic Committee.

December 23, 1976.

Hon. Hubert H. Humphrey,
Chairman, Joint Economic Committee,
U.S. Congress, Washington, D.C.

Dear Mr. Chairman: Transmitted herewith are two studies entitled "Thinking About Technology Policy for the Coming Decade" by Professor Nathan Rosenberg and "Technological Change and Future Growth: Issues and Opportunities" by Dr. Joseph F. Coates. These two studies comprise volume 9 of the Joint Economic Committee's study series "U.S. Economic Growth From 1976 to 1986: Prospects, Problems, and Patterns." This series forms a substantial part of the Joint Economic Committee's 30 anniversary study series.

While each paper addresses the same question—how will technological change influence future U.S. economic growth rates and pattern?—very differing perspectives are presented.

Professor Rosenberg presents a comprehensive examination of how technological change has influenced U.S. economic growth in the past.

His central hypothesis is that it is growth in the productivity of resources, and not mere growth in volume, that made technological change central to our past growth experience. He maintains that, in the long run, one of the most significant consequences of technological innovation has been to increase the size of the resource base itself by developing methods for the exploitation of previously unusable resources, and by the development of totally new materials such as plastics and synthetic fibers. The implication of this for the future is that the successful functioning of the American economy will continue to turn upon our capacity to develop techniques for the exploitation of the more abundant of the materials which make up our natural environment.

He devotes considerable discussion to the issue of government technology policy, suggesting that public policy toward technology may become more effective by addressing itself to more modest goals. He also suggests the desirability of a government technology policy involving the development of a greater capacity for shifting to alternative sources of material supplies so that we will retain a potential for more flexible policy responses to changing conditions. Another point which he emphasizes is that technological change and attendant productivity improvements enter the economy through many doors and take a wide variety of forms. He concludes that in spite of all the enormous contributions which technological change has made to our economic well-being, it is extremely important that we should not think of it as a potential "fix" for all of our economic problems.

Dr. Coates presents a highly optimistic assessment of the future of technological change in the United States. His analysis revolves about the movement of U.S. society into a postindustrial society with emphasis on knowledge-based industries that will stimulate major shifts in the nature and location of work, land use, and information. He expects major transformations in society, e.g., a substantial percentage of all work being done at home which in turn could provide cooperative team work for husband and wife which has major possibilities for a world substantially different from today's centrifugal family life. Many fundamental organizational changes in the work place and in the conditions for work are possible because of the major structural change in the labor force. He estimates that roughly 50 percent of the labor force is now in the business of generating, packaging, distributing, storing, interpreting, or in some other way manipulating data and information.

He expects more new opportunities in biological, psychological, intellectual, and social technologies which have been relatively little explored to date. This means that technologies will be developing which deal more directly with man as an organism and with the social relations among people. He postulates that the next wave of technological advance will therefore deal with the questions of improving the quality, diversity, and satisfaction in various consumer areas; and in meeting the collective needs, such as those of the handicapped, those suffering from unusual diseases, and the socially and culturally isolated.

He maintains that the principal role of government in assuring continuing benefits from technology is guiding the socially effective interplay of the basic variables: Land, labor, capital, resource avail-

ability and knowledge. To be socially useful, the interplay must be future-oriented, flexible, and information driven. As an example, he urges a role for government now in the study of the policy implications of the potential changes in the structure of work in society which he highlights in his paper.

The committee is deeply appreciative of the thorough and creative way in which these authors addressed the topic of technological change and economic growth. Professor Rosenberg is on the economics faculty at Stanford University and Dr. Coates is the Assistant to the Director, Office of Technology Assessment, U.S. Congress.

Dr. Robert D. Hamrin of the committee staff is responsible for the planning and compilation of this study series with suggestions and assistance from other members of the staff. The administrative assistance of Beverly Mitchell and Christal Blakely of the committee staff is also appreciated.

The views expressed are those of the authors and do not necessarily represent the views of the members of the committee or the committee staff.

Sincerely,

JOHN R. STARK,
Executive Director, Joint Economic Committee.

CONTENTS

THINKING ABOUT TECHNOLOGY POLICY FOR THE COMING DECADE

By NATHAN ROSENBERG* **

SUMMARY

It is a widely-accepted proposition that technological innovation has played a critical role in generating American economic growth. We now have reasonably reliable measures of the changing supplies of the various inputs as well as the growth in output for the American economy going as far back as 1840. A fact which emerges unmistakeably from these data is that the growth in total output and per capita output are far greater than can possibly be accounted for by the associated growth in input supplies—at least as these inputs are conventionally measured. America's long-term growth experience has produced something like a six-fold increase in output per capita over the period 1840–1960. For the last part of that period, 1920 to 1960, Kendrick has estimated that one third of the total economic growth was attributable to the growth in the supply of inputs and fully two thirds to an increase in the *productivity* of factor inputs. It is this growth in the productivity of resources, and not their mere growth in volume, which calls our attention to the centrality of technological change in our past growth experience.

Of course, a variety of factors other than technological innovations alone have contributed to the increase of resource productivity. At the same time it needs to be recognized that technological innovation has set into motion forces which cannot be adequately summarized by stating that such innovation has increased the productivity of *existing* resources. For, in the long run, one of the most significant consequences of technological innovation has been to increase the size of the resource base itself. Although our natural environment is fixed in a geological sense, it is not fixed in terms of its potential economic significance. Although uranium has existed in the earth's crust for a very long time, it has only become a resource in economic terms in the last couple decades. The same might be said with respect to offshore deposits of oil. Moreover, a major thrust of twentieth century technology has been the development of techniques for the exploitation of low-grade mineral ore deposits. These techniques have immensely expanded our supplies of usable iron, copper, lead, zinc, molybdenum and wood pulp, to name just a few.

Thus, a basic function of technological change has been to widen the resource base of the economy. It has done this not only by develop-

*Professor of economics, Stanford University.
**I have had the benefit of useful discussions on a variety of relevant matters with Moses Abramovitz, Richard N. Cooper, Stanley Engerman, Victor Fuchs, Hans Mark, David Mowery, Richard R. Nelson, and Raymond Vernon.

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ing methods for the exploitation of previously unusable resources, but also by the development of totally new materials, such as plastics and synthetic fibers. (Indeed, one of the most pervasive characteristics which has been associated with American economic growth has been the emergence of new industries producing new products, so that the growth in output has always been associated with significant changes in its composition as well.) It is apparent that the successful functioning of the American economy in the future will continue to turn upon our capacity to develop techniques for the exploitation of the more abundant of the materials which make up our natural environment. The financial support of research which holds promise of widening our scientific and technological capacity to utilize abundant natural materials should thus be accorded a very high priority.

The economic conditions which are likely to encourage innovative activity need to be more strongly emphasized. In our recent preoccupation with the contribution of technological progress to economic growth, there has been a serious neglect of the reverse relationship—the contribution of economic growth to technological progress. There seems little doubt that that contribution has been a powerful one in the past—that expectations of high rates of future economic growth have provided highly favorable environments to the willingness of individuals to commit resources to those activities which generate technological progress. Moreover, such favorable expectations have not only influenced the decision to commit resources to inventive activity; they have also positively influenced the *adoption* decision concerning inventions, once such inventions have been successfully developed. New technologies exercise their impact upon the productivity growth of the economy, *not* as a function of the volume of resources committed to the search process or even the actual achievement of new inventions. Rather, that impact is a function of the speed with which the new technology is diffused throughout the economy. New technologies generate productivity growth only to the extent that they are actually incorporated into the economic life of the society. In this sense it is the decision to adopt which is critical. Such decisions are, in turn, highly sensitive to expectations concerning market conditions and, in particular, to expectations concerning the adequacy of the demand for the product. Innovative activity, therefore, is not likely to flourish in a stagnating or slowly-growing economy with a substantial unemployed or underemployed labor force and an underutilized capital stock. Under these conditions the incentive to undertake inventive activity or to adopt new inventions will be weak and the incentive of workers to oppose the introduction of inventions, especially labor-saving inventions, will be strong. Measures on the macroeconomic level which will assure a sustained high level of economic activity will therefore strengthen both the incentive of business to introduce inventions as well as the willingness of workers to make the necessary accommodations involved in their introduction.

In some respects public policy toward technology may be much more effective if it addresses itself energetically to more modest goals and issues in addition to the big ones. In our preoccupation with the big questions we tend to neglect the fact that there are literally hundreds of things which we can do now, with our present technology, to achieve important goals. For example, while no one of the many ways in which we can, with our present technology, reduce our utilization of fuel,

will be highly significant to our aggregate utilization, cumulatively these measures would be enormously significant. Getting people to respond to these present possibilities for fuel savings requires a combination of forceful political leadership together with the willingness to introduce incentives into our economic life to induce people to reduce fuel consumption—smaller cars with less "performance," more extensive use of home insulation materials, substitution of glass bottles for aluminum beer cans, etc. At the same time, recent experience strongly suggests the desirability of a government technology policy involving the development of a greater capacity for shifting to alternative sources of material supplies in various areas, so that we will retain a potential for more flexible policy responses to changing conditions. Such flexibility is likely to be particularly important in activities where long lead times are involved. This necessity is, obviously, likely to become greater in an international environment where access to vital raw materials can be manipulated in response either to political considerations or the prospect of exploiting a monopolistic or oligopolistic advantage in world markets.

A point which requires great emphasis is that technological change and its associated productivity improvements enter the economy through many doors and take a wide variety of forms. Moreover, the location of these doors to shift periodically, so that any rigid mapping of the most significant relationships is bound to become outmoded over time—and not very long periods of time at that. It is of basic importance to the formulation of policy to recognize explicitly this diversity of routes and forms by which technological changes lead to improvements in productivity. Our failure to appreciate this diversity is due to a variety of causes: to the small size of individual improvements, to a frequent preoccupation with what is technologically spectacular rather than economically significant, and to the inevitable, related difficulty which an outsider has in attempting to appreciate the significance of alterations within highly complex and elaborately differentiated technologies. Finally, although we are becoming increasingly aware of the dependence of technology upon science, we are much less aware of the dependence of science upon technology. It needs to be remembered that progress in the realm of science is and always has been highly dependent upon technological improvements which enhance our capacity to observe and to experiment. This is particularly true in the realm of instrumentation. Our present knowledge of the natural world, ranging from microbiology on the one hand to cosmology on the other, would have been inconceivable without the microscope and telescope and the improvements which continue to be made in our observational capacities through further modifications of these instruments.

In spite of the enormous contribution which technological change has made to our economic well-being, it is extremely important that we should not think of it as a potential "fix" for all of our economic problems. The effective formulation of national policies can only be jeopardized by such excessive expectations. This is so not only because we will inevitably be disappointed and frustrated, but because, by placing excessive faith in the prospect for purely technological solutions, we will fail to explore other measures and alternatives which may offer greater, or more immediate, prospects for success.

Introduction

Perhaps the most common observation which foreigners have made over the years in commenting upon the distinctiveness of American civilization was its preoccupation with matters technological. De Tocqueville long ago called attention to the alacrity with which men in the upwardly mobile democratic environment of America rushed to the adoption of new techniques.

> As they are always dissatisfied with the position which they occupy, and are always free to leave it, they think of nothing but the means of changing their fortune, or of increasing it. To minds thus predisposed, every new method which leads by a shorter road of wealth, every machine which spares labour, every instrument which diminishes the cost of production, every discovery which facilitates pleasures or augments them, seems to be the grandest effort of the human intellect.[1]

I think de Tocqueville was fundamentally correct. It seems to me that much of the distinctiveness of the American experience has resided in the fact that the "New World" offered far fewer restrictions or inhibitions upon the introduction and spread of new technologies than was the case in Europe. Whatever may have been the historical reality underlying the much-vaunted "Yankee ingenuity," (and I am personally skeptical of the notion that Americans were in possession of some inherently greater inventive *capacity* than Europeans) there is little doubt that American society offered fewer roadblocks to the widespread adoption of inventions, once they were made. America's great past achievements were no doubt favored by a minimum of political interference to protect those who had a vested interest in the old technology. This, combined with rapidly growing population and markets, seems to have provided a powerful set of stimuli to technological innovation in many sectors of the economy.

Numerous studies by economists over the past twenty years have abundantly confirmed what has long been obvious to intelligent laymen—namely, that technological innovation has played a decisive role in generating the long, sustained growth in American living standards. And yet, in addressing ourselves to technological questions, and in particular in asking ourselves what we may reasonably expect of technology over the decade ahead, it is deceptively easy to get things out of focus. I believe that it is extremely important that we should learn not to expect of technology more than technology, by itself, can possibly deliver. The effective formulation of national policies can only be jeopardized by such excessive expectations. This is so not only because we will be disappointed and frustrated, but because, by placing excessive faith in the prospect for a technological "fix," we will fail to explore other measures and alternatives which may offer greater, or more immediate prospects for success.[2] In this respect I find the growing criticism of technology in recent years a salutary development insofar as it serves to disabuse us of the simplistic notion that technology can provide a neatly packaged solution for all of our problems.

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[1] Alexis de Tocqueville, *Democracy in America*, Arlington House, New Rochelle, New York, n.d. (Henry Reeve, translator), volume I, p. 45.

[2] For example, Victor Fuchs has recently argued, persuasively I think, that there are greater improvements in the health of the American population to be achieved through changes in life-style than through further expenditures upon new and highly-expensive medical technologies. The life-style and taste changes which he has in mind include such things as elimination of smoking, more bodily exercise, and greater attention to dietary matters to reduce obesity and other infirmities which are linked to patterns of food consumption. See Victor Fuchs, *Who Shall Live?*, Basic Books, New York, 1974.

Some of the critical voices, on the other hand, are excessively shrill, and seem to suggest that all technological innovations involve some sort of Faustian pact with the devil. Other critics link the bigness and narrow specialization of much modern industrial technology with the suggestion that such technology inevitably generates deep and pervasive frustration and alienation. At the same time it is asserted or implied that there are no inevitable tradeoffs between the pursuit of a more humane technology and a larger material output, that there are readily available alternative technologies of a smaller scale and richer human content which can be adopted without any substantial loss of material output. Needless to say, such important issues cannot be settled by mere assertion.

It is not my intention in this paper to deal with all the big questions—social, psychological and philosophical—which are posed by the continued utilization of modern industrial technologies. Rather, I intend to deal, on a more circumscribed level, with some questions concerning appropriate economic policy with respect to technology. I hope the outcome will be some illumination of the question of how we may more successfully guide technology toward the realization of certain widely-held national goals. However, I should perhaps say at the outset that I am not at all certain what are the implications for policy of *all* of the observations and comments which follow. Indeed, as I will emphasize, the range and diversity of the technologies employed today defy easy categorization. On the other hand, I am quite sure that effective policies toward technology cannot be developed without due attention to the kinds of considerations with which I will be concerned. Perhaps this is simply another way of recognizing that technological change is still not a very well understood phenomenon, that it continues to resist attempts to model it (much less to plan it) in a rigorous way, and that the further sudy of technological phenomena should, itself, be a high priority of government policy.

Some Conceptual Background

Technology, for present purposes, may be most usefully thought of as a form of knowledge. It is a very special form of knowlededge—that dealing with the transformation of the material environment into a flow of useful goods and services. If we view the economic process as those human activities which specifically involve the transformation of the material environment into goods and services which satisfy human needs, then we may think of technological change as increments to the stock of useful knowledge concerning the economic process. In the most elemental sense, these increments to human knowledge involve some improvement in the relationship between inputs and outputs. It is therefore convenient to think of technological change as advances in knowledge which make it possible to generate more output from the same volume of inputs, or the same volume of output from a smaller volume of inputs. Indeed, a large portion of the story of America's long-term economic growth can be told in precisely these terms. That story is one of pervasive and sustained improvements in resource (or factor) productivity. As a consequence, a unit of input in 1976—say a man-year of labor or an acre of land—typically produces a far greater output than did a corresponding input in 1776.

Thus, the long-term overall growth of the American economy involves two distinct processes. On the one hand, the volume of inputs has been growing. The history of the American economy is one of growth in total population and the labor force, rapid increments to the stock of capital goods and, up till roughly the end of the 19th century at least, vast new tracts of land brought into cultivation along with the westward movement of population. We would normally expect the total output of the economy to grow along with the growth in inputs. Such aggregate growth, however, need not involve a growth in resource productivity, but merely increments in output associated with the growth in inputs.

Much more interesting, however, is the fact that the American economy has grown over the years at rates far beyond what can be accounted for by the growing supply of inputs. From about 1840 we have reasonably reliable measures of the changing supplies of inputs as well as the volume of outputs. Leaving aside all the conceptual and methodological problems which are inevitably involved in such statistical exercises, a fact which emerges unmistakeably from these data is that the growth in total output and per capita output are far greater than can possibly be accounted for by the associated growth in input supplies—at least as these inputs are conventionally measured. John Kendrick, for example, estimates that between 1920 and 1960 some two-thirds of total economic growth in America was attributable to an increase in total factor productivity and one-third to the growth in the supply of factor inputs.[3] It is this growth in the productivity of resources, therefore, not their mere growth in volume, which calls our attention to the centrality of technological change in America's long-term growth experience. And, it should be noted, that long-term growth experience was one which produced something like a six-fold increase in output per capita over the period 1840–1960, or an annual rate of growth averaging slightly more than 1.5 percent.

This statement, so far, is not even a first approximation to the role of technology in American economic growth, because it at once claims too much and too little, if only implicitly. It would be grossly incorrect, first of all, to attribute all of the per capita growth of the American economy to technological change. The per capita output of an economy may grow for a variety of reasons not directly connected to technological phenomena. A larger proportion of the population may become productively employed due to such factors as changes in the age composition of the population or the increasing participation of females (both these factors have, in fact, played important roles in the American economy in the twentieth century). People may work harder, or more effectively, as a result of new payment schemes which raise their incentives, as in the case of piece rates or productivity bonuses. New personnel management techniques may raise productivity by achieving a more effective selection and assignment of workers to particular jobs. Purely organizational changes at the work place, or minor alterations in layout, may speed the flow of materials through a sequence of steps. New techniques of inventory control or a greater degree of product standardization may substantially reduce inventory requirements. Government policies may encourage the mobility of labor and thereby speed up the response to altered market

[3] John Kendrick, *Productivity Trends in the United States*, Princeton University Press, 1961, chapter 3.

conditions and, in so doing, improve the overall allocation of labor. Improvements in the operation of capital markets may increase the effectiveness with which capital is made available to potential innovators. None of these things falls under the rubric of what the economist ordinarily means by technological change, and it would only be an exercise in obfuscation to widen our definition of technology to include any of them. The fact is that there have been numerous forces contributing to American economic growth since colonial days. Although there are compelling reasons for believing that technological change has accounted for a large portion—perhaps most—of that total growth, we are still a long way from being able to separate out and to quantify that contribution with any pretense of precision.

The description of technological change as generating greater output per unit of input understates the impact of technology in two highly significant ways, one on the input side and one on the output side. The statement is, first of all, excessively static in nature. It fails to take account of the fact that the very definition of the word "input" in this context is not immutable. Our natural environment is fixed, at least in a geological sense, but it is not fixed in terms of its economic significance. Indeed, it is one of the most important features of technological change in American history that it has continually expanded the resource base of the economy. This has taken several forms. Improvements in techniques of extraction have made it possible to recover oil from depths of 20,000 feet or more, an accomplishment which was physically impossible not very long ago. Numerous innovations in exploration techniques (including the use of photographs from orbiting satellites) have had to a more rapid rate of discovery of mineral deposits. But, more generally, advances in technological knowledge have led to the development of techniques for the exploitation of materials which were formerly unexploited. Uranium was only a resource in the geological sense and not the economic sense as recently as 1940. The same was essentially true of even easily accessible petroleum deposits in, say, 1800. The point is that natural resources possess economic significance only as a function of technological knowledge, and improvements in such knowledge have regularly led to an expansion in the resource base in the economic sense. Another dimension of this process has become particularly conspicuous in the twentieth century as the supplies of high quality resources have been gradually exhausted. A major thrust of twentieth century technology has been the development of techniques for the exploitation of low-grade resources. Thus, the gradual exhaustion of the high grade iron ores of the Mesabi Range was followed by innovations such as methods of concentration and beneficiation (a technique for enriching the ore before it enters the blast furnace) which made possible the exploitation of the immense deposits of hard, low-grade taconites.

The flotation process, originally applied to the exploitation of low grade porphyry copper ores, has been applied to a wider range of ores, both of lower mineral content and more complex chemical forms. Techniques of selective flotation have played a major role in offsetting the decline in the quality of available resources, not only for copper, but for such important materials as lead, zinc and molybdenum as well. In 1880, the lowest grade of copper ore which we could utilize was 3 percent ore. Today it is 0.4 percent. Similar reductions have

taken place with respect to many other minerals. The great advances in sulphate pulping technology during the 1920s liberated the wool pulp industry from its earlier bondage to northern spruce and fir trees and made possible the exploitation of the more rapidly-growing but previously unusable southern pine. Doubtless a persistent theme in the future will be the search for technologies which will make it possible to rely upon highly abundant resources for the supply of essential materials. Harbingers of such shifts were the nitrogen fixation process which fixes nitrogen from the atmosphere and the increasing interest in sea water—already a source of magnesium—as a source of mineral inputs. There seems little doubt that, at some future date, the rising cost of increasingly scarce fossil fuels will lead to a major reliance upon the most abundant energy source of all, solar energy. We are still a very long way, however, from the development of the appropriate technology.

Thus, a basic function of technological change has been to widen the resource base of the economy. It has done this both by developing methods for the exploitation of low quality resources—resources which at an earlier period were regarded as "uneconomic"—and also by developing totally new materials—plastics, synthetic fibers, etc. It seems apparent that the successful functioning of the American economy, with its immense resource requirements, will turn upon our capacity to develop techniques for the exploitation of the more abundant of the materials which make up our natural environment. The financial support of research which holds promise of widening our scientific and technological capacity to utilize abundant natural materials should thus be accorded a very high federal priority. This should include techniques directed toward reducing dependence upon natural resource inputs by the recycling of used materials or the utilization of waste products.[4] The ultimate goal of this exploratory process is the situation which Harrison Brown has aptly characterized as follows: "The basic raw materials for the industries of the future will be seawater, air, ordinary rock, sedimentary deposits of limestone and phosphate rock, and sunlight. All the ingredients essential to a highly industrialized society are present in the combination of those substances." [5]

Historical Perspectives

A brief historical glance may lend some perspective to our present concerns. The sensitive and significant linkage between technological innovation and a heterogeneous resource base can be readily observed in the history of the iron and steel industry. From the 1850s on, a series of innovations occurred which continually altered the economic significance of natural resource deposits for the industry. The original

[4] It is worth noting here that many of our environmental problems are exacerbated by the *cheapness* of material inputs as compared to the prices of labor and capital. Thus, we may observe that two of the major concerns of environmentalists are really based upon conflicting assumptions about relative resource prices. The pollution problem is often based upon the cheapness of raw material inputs, making recovery uneconomic. The resource exhaustion problem, on the other hand, is based upon the assumption of inexorably rising prices of resources. But, if materials prices were much higher, we could be saving our old newspapers, collecting discarded beer cans, and hauling off to the junkyards the tens of thousands of automobiles which are abandoned on our roads and highways every year—or at least it would be worth *someone's* effort to provide these services for us. An interesting implication, therefore, is that a rise in raw material costs may be expected to *reduce* the severity of some of our pollution problems.

[5] Harrison Brown, *The Challenge of Man's Future*, Viking Press, New York, 1954, p. 218.

(acid) Bessemer process could be used only to refine materials fulfilling certain precise chemical conditions—the process required iron free from phosphorus content (the later basic Bessemer process, by contrast, required ores of a *high* phosphorus content, but the United States did not possess large deposits of such ores. and the process never became a significant one in this country). The basic open hearth furnace of the 1880s, however, was capable of exploiting a very wide range of inputs in steelmaking (in addition to permitting a more precise degree of quality control than was possible with the Bessemer technique). In particular, it could utilize ore of almost any proportion of phosphorus content, and its availability made it possible to exploit a much wider band of the available spectrum of the gigantic Lake Superior iron ore deposits. Moreover, the process could utilize a high proportion of scrap as a material input, a consideration of great and increasing significance in locations with ready access to such supplies. The growing abundance and cheapening of scrap in the twentieth century induced research into methods of increasing the proportion of scrap used in oxygen converters. With the recent development of the electric furnace we now have a technique for producing steel entirely without iron ore since such furnaces can operate with a 100 percent scrap charge. Thus the potential supplies of inputs into the steelmaking process have been steadily widened, even to include the junkyards.[6]

The interaction between technological change and the natural resource base can be seen even more dramatically in Europe. The original Bessemer process could be employed only when certain chemical conditions were precisely fulfilled. The method required iron which was free from phosphorus content. The fact that Bessemer's methods could only refine materials which fell within certain narrow limits of chemical analysis had major economic consequences, imparting a strong comparative advantage to those regions possessing the non-phosphoric ores. Britain's (acid) Bessemer process grew rapidly upon the exploitation of her large deposits of non-phosphoric haematite ores. On the other hand, Germany and France had only very limited deposits appropriate for the Bessemer technique and Belgium had none. The Bessemer technique was useless for the exploitation of Europe's massive deposits of high-phosphorus ore in Lorraine and Sweden.

This British advantage, however, proved to be short-lived. The Thomas-Gilchrist technique, introduced in 1879 after a long search for methods which permitted the exploitation of phosphoric ores, drastically altered comparative advantage in favor of Continental steel producers. Their introduction of a "basic" lining for an "acid" one vastly expanded the range of ores which could be utilized in modern steel-making technologies—making possible the intensive exploitation of Europe's great phosphoric ore deposits.[7] The Thomas-Gilchrist technique thus made possible a great expansion of steel production in Germany, France and Belgium after 1880—an expansion involving both the basic Bessemer and basic open hearth methods. Thus, what

[6] In this respect the steel industry has already taken giant strides in the direction of recycling.

[7] Whereas the acid Bessemer process required low phosphorus content, the basic Bessemer process required a high phosphorus content—more than 1.5 percent phosphorus. Although this technique was well-suited to German ores, it was not as well suited to Britain's phosphoric ores, which turned out now to have insufficient phosphorus for the basic process. See Peter Temin, *Iron and Steel in Nineteenth Century America*, M.I.T. Press, 1964, chapter 6 for a good discussion of the Bessemer and post-Bessemer innovations in steelmaking.

appears as a rather insignificant and humdrum technological event—the mere substitution of a new material for an old one in the lining of the furnace—was, in fact, an event of immense economic and geopolitical significance. Germany's swift and spectacular emergence as an industrial power was based directly upon the rapid growth of her steel industry in the 1880s and 1890s—a growth which had, in turn, been made possible by the introduction of the basic lining and the drastic redefinition of the natural resource base which flowed from it.[8]

The gradual exhaustion of the richest iron ore supplies in the U.S. and elsewhere in the twentieth century shifted the economic payoff away from the earlier concern over phosphorus content and toward the development of methods which would make possible the exploitation of low-grade iron ore. The result has been the growth of a highly sophisticated technology focusing upon the use of poor-quality inputs. Ores with a low iron content are now subjected to a process of beneficiation—an upgrading of their iron content before they are introduced into the blast furnace. Waste materials such as clay, gravel and sand are removed and the ores are crushed and washed, so that the material entering the blast furnace is cleaner and more uniform in quality. The implications of such techniques have been very great because they have made possible the utilization of huge resource supplies which would formerly have been ignored.

> One of the recent and significant beneficiation achievements has been the development of a process to extract high grade iron ore from a rock called taconite, one of the hardest in the world. There are billions of tons of it in the area around Lake Superior. Taconite contains only about 22 percent iron, and until recently the cost of extracting iron from it was prohibitive. But during the past couple of decades improved methods of extracting iron from taconite ore have been developed, and now millions of tons of high grade iron ore, produced from taconite in the form of pellets ready for the furnace, are shipped from the Lake Superior region.[9]

These developments in iron and steel are by no means unique. Although discussions of the impact of new technologies usually concentrate upon resulting improvements in productivity, it is essential to note that the main technological innovations in the iron and steel industry over the past century also had the immensely important effect of substantially widening the range of usable natural resource inputs. New techniques elsewhere have, in effect, similarly augmented our "dwindling" supply of other minerals in parallel ways.

The point here is of basic importance in understanding the significance of technological change. Such changes alter the economic significance of the physical environment so extensively that one cannot really discuss the role of natural resources in economic activity without first carefully specifying the level of technological knowledge and sophistication. To put the point somewhat differently, the growth of technological knowledge generates information which makes it economically worth while to exploit resources which were formerly considered of such poor quality as not to be worth troubling with. For this reason, discussions which ask how long it will take, at present or extrapolated consumption rates, before we run out of a particular natural resource are usually not very interesting. What the natural

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[8] See J. C. Carr and W. Taplin, *A History of the British Steel Industry*, Harvard University Press, 1962, chapter XIX, appropriately titled "Lost Pre-eminence."

[9] W. N. Peach and James A. Constantin, *Zimmermann's World Resources and Industries*, Harper and Row, New York, 1972, p. 448.

environment usually offers are limited deposits of resources of high quality and then a gradually declining slope toward lower grade resources, which typically exist in abundance. It is a geological fact of life that there is a much greater profusion in the earth's crust of low grade than of high grade resources. Even such terms as "high grade" or "high quality" are often misleading since they refer to chemical composition and describe properties which may or may not have economic significance. Thus, anthracite coal has usually been regarded as higher quality than bituminous coal because it has little gas and other impurities, such as sulphur. But, from the point of view of its use as a blast furnace fuel, the low gas content was for many years a serious disadvantage because it made ignition very difficult. As a result the rich anthracite deposits in the eastern United States were unusable in the blast furnace until the introduction of Neilson's hot blast during the 1830s. Even so, this "high quality" coal was soon displaced by large "low quality" bituminous deposits when the westward movement of population made these deposits more readily accessible.

In all of these ways then, the expansion of technological knowledge transforms the meaning and significance of what are rather colorlessly described as "inputs". Equally drastic changes, however, have been taking place on the "output" side. It is immensely convenient to be able to characterize technological change as constituting an improvement in some relationship between inputs and outputs. If all technological improvements were simply cost-reducing process innovations, this would make it easier to deal with the economic consequences of technology. The growth in the economy's output would involve alterations in its composition—i.e., changes in the relative importance of different categories of goods. But the changes would be purely changes of quantity and not quality—there would be no entirely new products or significant quality changes of existing products.

Although such a situation would simplify the life of the national income statistician or anyone attempting to reduce technological change to purely quantitative treatment, it is manisfestly not an accurate characterization of the long-term impact of technological change. Any treatment of the impact of technological change on American society over the past 200 years which took no cognizance of the new products generated by that technology would be missing what has been, arguably, its most significant dimension.

American society and life in the 1970s is different from the world of Franklin, Washington and Jefferson, not just because we have more of the same bundle of goods consumed by these eminent gentlemen. It is different also because we have available an immensely expanded range of goods of a nature and quality literally undreamed of in the 18th Century. Medical technology and public health measures over the past century, culminating in the development of antibiotics, have brought with them the conquest of infectious diseases and a vast increase in life expectancy. Aspirin, antihistamines, tranquilizers, novocaine and anesthesia have brought with them a remarkably enhanced degree of control over pain, discomfort and nervous tension (the last doubtless one of the less desirable concomitants of modern technology). A sequence of contraceptive technologies, of which "the pill" is merely the most recent, has provided increasingly effective control over human reproduction. Furthermore, a host of technological changes have per-

mitted a greater enjoyment of leisure time, longer life, and a wider range of freedom concerning locational choice. The air conditioner, for example, has made it possible for larger populations to maintain permanent residence in such "sunbelt" locations as Texas, Arizona, and Florida, as well as greatly improving conditions of work for large numbers of people. On the other hand, twentieth century technology has also generated weapons of an awesome degree of destructiveness. It would be difficult indeed to find any yardstick with which to provide convincing—or even plausible—measures of the impact of these new technologies.

The inability to take qualitative changes adequately into account is thus one of the most serious limitations in our national income and product accounts—a matter of increasing concern in recent years. But there is another highly important interaction between technological change in the form of product innovation and economic growth. Much technological innovation has been associated with the rise of new industries producing new products. This has not been a random or adventitious association. Rather, high aggregate growth rates in an industrial economy are a reflection of a continuous shift in product and industry mix. As Simon Kuznets has emphasized, all rapidly growing industries eventually experience retardation in growth as the cost-reducing impact of technological innovation in each industry eventually approaches exhaustion. A continuation of rapid growth therefore requires the development of new products. In view of the typically low long-term income and price elasticity of demand for old final consumer goods, further cost-reducing innovations in those industries will have a relatively small aggregative impact. In Kuznets' view: ". . . (A) sustained high rate of growth depends upon a continuous emergence of new inventions and innovations, providing the bases for new industries whose high rates of growth compensate for the inevitable slowing down in the rate of invention and innovation, and upon the economic effects of both, which retard the rates of growth of the older industries. A high rate of over-all growth in an economy is thus necessarily accompanied by considerable shifting in relative importance among industries, as the old decline and the new increase in relative weight in the nation's output." [10]

The preoccupation with product innovation is obviously not a recent development. As early as 1951 Gordon Bloom, reporting on his own survey of industrial research laboratories, disclosed that ". . . only about 25 percent of regular industrial research budgets are devoted to cost reduction projects, while in the neighborhood of 75 percent is allocated to product improvement and development of new products." [11] The general thrust of more recent surveys is similar. They indicate that, if research and development expenditures may be taken as a reliable guide, American business firms are much more concerned with product innovation than with process innovation. For example, a McGraw-Hill survey indicated that, for the year 1975, industry ex-

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[10] Simon Kuznets, *Six Lectures on Economic Growth*, The Free Press, Glencoe, 1959, p. 33. For a more detailed presentation, see Simon Kuznets, *Secular Movements in Production and Prices*, Houghton Mifflin, Boston, 1930.

[11] G. F. Bloom, "Wage Pressure and Technological Discovery," *American Economic Review*, September 1951, p. 607. Bloom also added that ". . . the percentage of industrial research budgets devoted to product improvement is growing . . ."

pected that 37 percent of its R&D expenditures would be devoted to the development of new products, 48 percent to the improvement of existing products, and only 15 percent to the development of new processes.[12] On this basis it seems apparent that continued product innovation is the primary justification underlying the expenditure of research and development funds by private industry.

Of course, whether an innovation is classified as a new product or a new process will often depend upon the vantage point from which the innovation is considered. This is particularly the case in a highly specialized industrial economy where inter-industry transactions loom very large. A process innovation—say a numerically controlled machine tool—will represent a cost-reducing innovation to the firm using the machine tool for the production of airplane components; but it will represent a product innovation to the firm whose business it was previously to produce manually-operated machine tools but which now produces numerically controlled machine tools. New fertilizers or pesticides represent product innovations to one set of firms but constitute cost-reducing process innovations to the agricultural sector of the economy. Indeed, we are dealing here with a central feature accounting for much of the technological dynamism of advanced capitalist societies. Producers of capital goods have a strong and pervasive incentive, in terms of their own profit prospects, to develop new capital goods products which will constitute cost-reducing process innovations to the industrial *users* of such intermediate products.[13]

Present Concerns Over Technology

The growing concern over the adequacy of our technological performance in recent years has been based primarily upon two assertions. The first is the evidence of increasing success of foreign producers in displacing American "high-technology" products both at home and in foreign markets. The second is that there has been a slowing down in the rate of productivity growth, beginning in the second half of the 1960s.

In the post World War Two period up to the early 1960s, it was almost universally believed that the United States enjoyed a decisive and unassailable technological superiority over the other highly industrialized nations of the world. Although the notion of a "technol-

[12] *20th Annual McGraw-Hill Survey: Business' Plans for Research and Development Expenditures, 1975–1978,* McGraw-Hill Publications Company, New York, 1975. For comparable evidence for the U.K., see *Industrial Research in Manufacturing Industry 1959–60,* Federation of British Industries, 1961.

[13] "It is the producers of capital goods who have the financial incentive and therefore provide the pressures (marketing, demonstration) to persuade firms to adopt the innovation (which they produce). Creating a capital goods industry is, in effect, a major way of *institutionalizing* internal pressures for the adoption of new technology. In America the producers of capital goods have always played a major role in persuading and educating machinery users about the superiority and feasibility of new techniques. This is an extremely important activity in overcoming the inevitable combination of inertia, ignorance, and genuine uncertainty which surrounds an untried product. The introduction of the diesel locomotive by General Motors is a classic case in point. In the United States both the railroad companies and the locomotive producers were extremely skeptical of the diesel engine and resisted its introduction. It took great promotional effort on the part of GM, which developed the diesel, to induce the railroads even to consider and experiment with the innovation. This kind of promotional activity, on the part of capital goods industries with a strong personal motive to gain acceptance for their product, seems to have been a critical factor in the American experience." Nathan Rosenberg, "Economic Development and the Transfer of Technology: Some Historical Perspectives," *Technology and Culture,* October 1970, pp. 565–66.

ogy gap" was never precisely defined,[14] it was widely accepted that the United States possessed an unquestioned technological superiority and that this superiority was fraught with the most dangerous economic and political consequences for other countries, particularly those of western Europe. At the very least, the view was widely held in western Europe that only a drastic "overhauling" of political machinery would make it possible to face up to "The American Challenge" as J. J. Servan-Schreiber characterized it in his widely-discussed book, published in 1968. Failing some decisive action, western Europe was destined to slip into the status of an American colony, totally dependent upon the United States for both economic and technological leadership.

The speed with which these dominating views were displaced by something approaching their polar opposite was breathtaking. Within a couple of years the view of American technological hegemony gave way to the view that the United States was being overtaken throughout a wide range of high technology exports—and even many low technology exports—by the burgeoning economies of western Europe and Japan. By 1974 a distinguished American economist published an article bearing the somewhat ominous title "An American Economic Climacteric?" [15] and proceeded to suggest an affirmative answer to his question.[16]

A more judicious view would begin with the recognition that the extraordinary circumstances of World War Two and its aftermath made it possible for the United States to increase its technological lead over Europe—a lead which unquestionably persisted from 1940 to about 1960. After 1960 the gap began to narrow. Characteristically, Europeans began to articulate their concern over American leadership at precisely the time when they were making significant inroads into that leadership. But it should be apparent that American technological leadership could not possibly persist "across the board." Indeed, it reflected extraordinary national conceit in the first place to regard such American technological dominance as being, in any sense, natural.

I would suggest that the increasing effectiveness in recent years of European and Japanese competition reflects not only the resurgence of their economies after the cataclysmic events of World War Two: from a longer historical perspective of a century or more, America's great success as an exporter of manufactured goods was solidly based

[14] The term "technological gap" was frequently used rather indiscriminately to describe any situation where there was a substantial *productivity* gap between the United States and Europe. To describe such a gap as a technological gap is, of course, to beg the question of the cause of the productivity gap. In fact, much of the discussion of the "technological gap" was focussed upon superior American *managerial* practices.

[15] Charles Kindleberger, "An American Economic Climacteric?" *Challenge*, January–February 1974.

[16] For a useful discussion of the rapid transformation of perceptions, see Harvey Brooks, "What's Happening to the U.S. Lead in Technology?" *Harvard Business Review*, May–June 1972. Brooks states: "What are we seeing, in fact, is the emergence of an increasingly international science, technology, and economic system in which the very concept of superiority and inferiority has less and less meaning. The industrialized countries as a group are approaching some sort of saturation relative to past growth, and the United States, as the most advanced nation in per-captia GNP, has entered the transition phase a few years in advance of its competitors.

"Other industrialized nations most likely will continue to close the gap, but will approach a common asymptote with us—that is, reach the same approximate level—rather than pass us on a steeply rising curve. Of the factors in the United States that have slowed the growth of science, generated the reaction against technology, and produced the disenchantment with productivity, many are also visible in other advanced countries," *Ibid.*, p. 112.

upon an unsurpassed endowment of natural resources. This endowment was far superior to that of any other industrial nation. We are now observing the effects of a narrowing of factor price differentials between the United States and Europe, especially the historical cheapness, in America, of raw materials as compared to labor and capital.

A century ago American labor was very expensive relative to cheap raw materials, and America's technological direction needs to be understood as an exploitation of the comparative advantage which flowed from this situation. More recently, rising labor costs in Europe and the rising relative cost of raw materials in the United States have been leading to a convergence in relative factor prices between the two continents. We are, in this sense, observing some of the consequences of America's loss of its earlier great natural resource comparative advantage. The sudden Arab oil embargo only dramatized a longer and more pervasive transformation. Ironically, therefore, whereas many Europeans were only recently complaining of the "Americanization" of Europe, the reality of the situation could be more accurately described as the "Europeanization" of America. To be sure, we continue to retain some very important advantages, such as those provided by our large endowment of high-quality agricultural land which still provides the basis for the export of resource-intensive products, but our position of *overwhelming* natural resource superiority is largely a thing of the past.[17] Nevertheless, our preoccupation with high technology products should not blind us to the wide range of economic opportunities which are still available to us in more traditional areas. Our capacity to export large volumes of agricultural products, as the Soviet and Chinese grain failures of 1972 served to remind us, is likely to remain one of our most decisive assets in the international economic arena in the years ahead.

The second cause for the increasing concern over the adequacy of our technological performance is the allegation that the rate of productivity growth of the American economy experienced a significant decline beginning in the second half of the 1960s.

It should be said, first of all, that a decline in the rate of growth of output per worker need not *necessarily* and by itself be a matter of public concern. For example, when sufficiently high levels of income and affluence are attained, people may exercise a preference for greater leisure or for working at a slower pace. Such a preference, if acted upon, may lower the rate of growth of output per worker, but it is not necessarily undesirable. Similarly, the introduction of child labor laws or an increase in the proportion of our population going on to higher

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[17] The analysis of international trade flows which, in the context just described, seems to me to make the most sense, is the product cycle literature emerging out of Raymond Vernon's seminal article, "International Investment and International Trade in the Product Cycle," *Quarterly Journal of Economics*, May 1966. Vernon attempts to go beyond the conventional comparative cost analysis which accounts for the composition of trade flows among countries in terms of differences in resource endowments and factor prices. The essential novelty of his approach is his attempt to incorporate the life cycle of a product—new product, maturing product, standardized product—into the analysis of observable shifts in international trade and investment. In doing so he accords a prominent place to the nature of domestic demand and the gradual maturing of the new product. His hypothesis predicts that the United States will tend to be an exporter of high income and labor saving products *in the early stages of the life cycle of such products* and an importer of them at the later stages. Vernon's analysis serves to underline once again the importance of studying the implications of product innovation as well as cost-reducing process innovation to which economists have devoted most of their attention. See also Raymond Vernon (ed.) *The Technology Factor in International Trade*, Universities-National Bureau Conference Series No. 22, 1970.

education would both have the immediate effect of slowing down entry into the labor force and would unfavorably affect the economy's output. Alternatively, certain kinds of economic activities may be discontinued, or discontinued at specific locations, because of their undesirable environmental impact. We might decide, for example, to discontinue a strip mining operation because of its unsightly consequences, even though it meant that we had to substitute higher cost energy sources. Or we might prohibit the location of a paper mill or a power generating plant on an attractive body of water because of the destructive ecological impact resulting from a large quantity of effluents. Similar observations might be made concerning measures taken to ensure worker or consumer safety. Obviously the individuals making up our society have many goals, some of which can be attained only at the expense of measured national output. Consequently, a slowing down in the rate of growth of GNP per worker should not be regarded, *ipso facto*, as a cause for national concern or as evidence of the need for some new government policy.

One need not search far for reasons for being skeptical of the view that policies should be formed *solely* in terms of their impact upon measured GNP.

It is by no means obvious, then, that a slowing down in the rate of growth of productivity is necessarily a reflection of technological failure. In fact, a variety of reasons have recently been advanced for the apparent retardation in the rate of growth of labor productivity seen in Table I.

TABLE I [1]

	Annual growth rate of output per man hour (private domestic economy)—percent
1899–1929	1. 7
1929–57	2. 4
1948–55	3. 11
1955–65	2. 51
1965–71	1. 88

[1] First two rows, John Kendrick, *Productivity Trends in the United States*, Princeton University Press, 1961, p. 72. Rows 3–5, William Nordhaus, "The Recent Productivity Slowdown," *Brookings Papers on Economic Activity*, 3, 1972, p. 493. Edward Denison's estimates for the whole economy show an even sharper decline in the growth rates of national income per employed person. This figure fell from 2.51 percent for the period 1953–64 to 1.57 percent for 1964–69. See Edward Denison, *Accounting for United States Economic Growth 1929–1969*, The Brookings Institution, 1974, p. 124.

And, of course, the effectiveness of any policies introduced for the purpose of raising the rate of productivity growth is likely to be sensitive to our analysis of its causes. Christensen, Cummings and Jorgenson, for example, have argued that there was a slowing down in the rate of growth of the capital-labor ratio during the 1960s.[18] Such an analysis suggests the desirability of policies directed toward raising the proportion of our resources devoted to capital formation, perhaps a more favorable treatment of profit receipts, the raising of surpluses through the government sector, etc. Kendrick has suggested that a factor in the decline in productivity growth between 1966 and 1970 was the decline in the proportion of expenditures upon *intangible*

[18] Laurits Christensen, Dianne Cummings, and Dale Jorgenson, "An International Comparison of Growth in Productivity, 1947–73," unpublished paper prepared for presentation at the Conference on New Developments in Productivity Measurement, Williamsburg, Va., Nov. 13 and 14, 1975.

capital, particularly upon R&D, which peaked in the mid-1960s.[19] Others have argued that there was a demographic phenomenon at work, leading to an altered composition of the labor force.[20] According to this view the significant factor was a rise in the proportion of young people (and women) in the labor force.

To the extent that the slowing down of the rate of growth of output per worker was due to a rising proportion of less productive young people entering the labor force—a consequence of the "Baby Boom" of the post-war decade—it is obviously self-correcting, and no new policy measures are called for. Nordhaus and others have argued that the slowing down of productivity growth is a consequence of shifts in the composition of output, itself the result of the changing composition of demand associated with rising incomes.[21] Nordhaus' study finds no widespread evidence of a slowdown of productivity growth in individual industries. However, he concludes that aggregate growth has slowed down because of sectoral shifts in output and employment out of high productivity sectors and into low productivity sectors—essentially the service industries. The analysis raises a host of troublesome questions,[22] not the least of which is the reliability of our established procedures for measuring the output of the service industries. In particular, how do we measure output and productivity in the large and growing government sector? The present measurement conventions of the Commerce Department undoubtedly impart a downward bias to measures of productivity growth in the government and other service sectors, and it seems therefor that our current measures may not be a fully satisfactory guide to policy issues. How should we measure the output of the educational sector? What exactly *is* its output? [23] Are we prepared to regard an increase in the student/teacher ratio as evidence of the increasing productivity of teachers? (For your *own* children?)

It seems to be particularly true of many services that efforts to increase their productivity are associated with distinctive, and often objectionable, alterations in their nature and quality. Finally, the slower rate of growth of output per worker may simply be a reflection of short-term cyclical fluctuations and may not therefore portend any serious decline from higher long-term growth trends.

Having said all this, technological change remains a major indispensable source to which we must turn in seeking to generate high rates of productivity growth, as well as solutions to a wide range of

[19] John Kendrick, "The Productivity Slow-Down," *Business Economics*, September 1971, pp. 10–11. It would be surprising, however, if productivity growth in the economy as a whole could be so closely linked to annual variations in R&D. And, from a longer time perspective, Arrow has stated: "The enormous acceleration in R&D (even apart from governmental support) over the past 30 years has been accompanied by only a mild increase in the rate of increase of total factor productivity and by no increase at all in inventions, at least as measured by patents." Kenneth Arrow, *Science*, 9 May 1969, p. 700.

[20] George Perry, "Labor Structure, Potential Output, and Productivity," *Brookings Papers on Economic Activity*, 3, 1971.

[21] William Nordhaus, "The Recent Productivity Slowdown," *Brookings Papers on Economic Activity*, 3, 1972; William Baumol, "The Macroeconomics of Unbalanced Growth," *American Economic Review*, June 1967.

[22] A skeptical view of the Nordhaus finding, based upon a simulation analysis to determine the quantitative significance of the intersectoral shifts, is presented by Michael Grossman and Victor Fuchs, "Intersectoral Shifts and Aggregate Productivity Change," *Annals of Economic and Social Measurement*, 2/3, 1973.

[23] One of the peculiarities of the service sector is that productivity is determined by the behavior of the "consumer" as well as that of the "producer." Productivity in education depends not only upon the activity of the teacher, but upon that of the individual student as well. See Victor Fuchs, "The First Service Economy," *The Public Interest*, Winter 1966.

specific problems, in the years ahead. The desirability of productivity growth is, in my view, in no way diminished by the increasing concern over environmental problems. Improvements in environmental quality will require a diversion of resources from other activities into a wide range of programs for dealing with pollution in its various forms. The prospects for achieving such diversions, I think it is fair to say, will be greater where they do not involve substantial reduction in real per capita incomes. That will require continuous further productivity growth. Perhaps even more important in the long run, resources will need to be committed to modifying our present technologies and perhaps developing wholly new ones, technologies which will not be accompanied by so many of the obnoxious side effects which plague those presently at our disposal. The possibility for achieving these more recently articulated goals will therefore depend very much upon our capacity for controlling and directing our technological capacities in specific directions. I turn now to some considerations which are relevant to the formulation of policies directed toward these ends.

The Formulation of Technology Policies

The first thing that needs to be said is that the rate and direction of technological activities are highly responsive to market forces. The *limitations* of market forces in generating an optimal allocation of resources with respect to knowledge-producing and new-technology-producing activities have been carefully scrutinized over the past 20 years, and need not be rehearsed here.[24] The basic point is that even a purely competitive economy will underinvest in knowledge-producing activities when the outcome of these activities is highly uncertain, when succesful outcomes are likely to generate widespread and highly diffuse payoffs, and when the market and the institutional context do not facilitate the private appropriability of those payoffs. American history, going back to the establishment of our land-grant college system and agricultural experiment stations, and even farther back to the establishment of our patent laws nearly two hundred years ago, is full of attempts to develop new institutional forms to accommodate various categories of "market failure." In our proper concern with the imperfections of market forces in providing a socially optimal system of incentives, however, we should not forget that the market remains an immensely powerful device for marshalling resources into productivity-increasing activities.

In order to be successful, policies should be devised with an awareness of the sensitivity of inventive activity to the forces of both demand and supply. At any time, demand and supply considerations interact to provide, for the whole range of inventive possibilities, a configuration of profit expectations which, in an economy such as ours, shape the allocation of inventive resources. On the demand side, the need for any given invention will be influenced by (*a*) any increase in revenue flows or (*b*) any reduction in expenditure flows which are associated with the employment of the invention. The expected returns to an invention, then, will be affected by any of the forces which alter the demand for the final product to which the invention may be related.

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[24] Richard Nelson, "The Simple Economics of Basic Scientific Research," and Kenneth Arrow, "Economic Welfare and the Allocation of Resources for Invention," both reprinted in Nathan Rosenberg (ed.), *The Economics of Technological Change,* Penguin Modern Economics Readings, 1971.

Such forces might include changes in per capita incomes, changes in family size and age composition of the population, urbanization, etc.[25] On the supply side, the prospective cost of an invention will depend upon the availability of all the factors involved in inventive activity. Such costs, therefore, will reflect the scarcity or abundance of these factors, and, in addition, any qualitative aspects which are relevant for the productive process. The capacity to solve certain kinds of problems, which is the essence of inventive activity, will depend upon the supply of labor possessing the requisite human skills, training and talents, whether acquired through systems of apprenticeship, on-the-job training, or formal education; and upon the state of organized technological and scientific knowledge which can be made available to potential inventors.[26]

Government policies toward technology need to be formulated in terms of the impact which they will be likely to exercise through these two sets of forces. However, in an economy such as ours where the capacity to generate a high level of inventive activity is demonstrably strong, a primary goal should be simply to ensure that the appropriate channels are kept open, that, for example, innovative activity is not discouraged by legal or monopolistic barriers to entry into an industry, by obsolete building codes, or by trade union impediments to the utilization of new inventions. With respect to our present energy concerns, at the very least government regulations which have the effect of restricting the upward movement of natural gas or petroleum product prices should no longer be tolerated. Artifically low prices encourage rather than discourage consumption and they seriously weaken the incentive to explore for new sources of fossil fuel deposits or to invest in the development of new technologies which offer a prospect for increasing future energy supplies.

In the past couple years we have been treated to the rather unedifying spectacle of government by exhortation. The public has been urged to alter its behavior in ways which will more directly accord with a changed definition of the national interest. At the same time, however, very little has been done to provide the public—industry as well as households—with economic incentives to bring about the desired modification of behavior. There is much talk of energy conservation but fuel prices remain artifically low, largely as a result of government regulation. Indeed, some of the goals, such as energy conservation, pollution control and safety, often involve mutually-conflicting policies. Automobile emission control devices reduce pollution but raise energy consumption, heavier cars are arguably safer to operate but also raise energy consumption. The goals being laid down by a growing number of government agencies are often inconsistent but, even more often, they fail to enlist the self-interest of the individuals concerned. The result, more often than not, is a growing sense of cynicism and frustration which contribute to an increasing degree of hostility to, and alienation from, the federal government.

On the macroeconomic level it needs to be emphasized that innovative activity is not likely to flourish in a stagnating or slowly-growing

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[25] For an authoritaitve treatment of the role of demand forces in shaping inventive activity, see Jacob Schmookler, *Invention and Economic Growth*, Harvard University Press, 1966.

[26] For a discussion of the role of supply side variables in the inventive process, see Nathan Rosenberg, "Science, Invention and Economic Growth," *Economic Journal*, March 1974.

economy with a substantial unemployed or underemployed labor force and an underutilized capital stock. Under these conditions the incentive to undertake innovative activity will be weak and the incentive of workers to oppose the introduction of inventions, especially labor-saving inventions, will be strong. Monetary and fiscal measures which will assure a sustained high level of economic activity will therefore strengthen both the incentive of business to introduce inventions as well as the willingness of workers to make the necessary accommodations involved in their introduction. This point deserves particular emphasis because, as a result of the preoccupation in recent years with "growth accounting" and the attempt to measure the contribution of technological progress to economic growth, there has been a serious neglect of the reverse relationship—the contribution of economic growth to technological progress. There seems little doubt that that contribution has been a powerful one in the past—that expectations of high rates of future economic growth have provided highly favorable environments to the willingness of individuals to commit resources to those activities which generate technological progress.

But this has been so not only at the level where individuals and firms have made commitments of resources to developing new technologies—i.e., inventions. It has also applied with respect to *adoption* decisions concerning these new technologies. The point cannot be overemphasized that new technologies exercise their impact upon the productivity growth of the economy, *not* as a function of the volume of resources committed to the *search* process or even the actual achievement of new inventions. Rather, that impact, given the productivity differential between the new technology and the one which it displaces, is a function of the speed with which the new technology is diffused throughout the economy.[27] New technologies generate productivity growth only to the extent that they are actually incorporated into the economic life of the society. In this sense it is the decision to adopt which is critical. Such decisions are, in turn, highly sensitive to expectations concerning market conditions and, in particular, to expectations concerning the adequacy of the demand for the product.

It is my distinct impression that, in many areas of our economic life today, and perhaps most conspicuously in the energy field, important innovations are being held up, not by supply side considerations—that is to say, by the technical *incapacity* to innovate—so much as by the pervasive uncertainties over the state of future demand. Such uncertainties understandably generate a strong reluctance to undertake large-scale financial commitments which will need to be strung out over long time periods. I believe that one possibly fruitful route through which technological improvements of a desired kind can be produced is by government measures to reduce the uncertainty over the size of the future demand for certain classes of products. Governments, federal, state and local, can shape the direction of technological change in such areas of increasing concern as environmental pollution and energy by offering contractual guarantees which will assure the existence of markets for technologies which will meet certain performance specifications and pollution-reducing requirements. Or by commitments which will provide certain minimum price

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[27] See Nathan Rosenberg, "Factors Affecting the Diffusion of Technology," Chapter 11 in Nathan Rosenberg, *Perspectives on Technology*, Cambridge University Press, 1976.

guarantees or other financial assurances for firms undertaking to develop the technology for the exploitation of new energy sources such as coal gasification, liquefaction, or oil shale. The development of such alternative energy technologies is characterized by long lead times, technological uncertainties, and very large scale financial commitments. The willingness of private industry to undertake such commitments can be vastly strengthened by the assurance of some minimum demand for the eventual product, if it meets appropriate performance specifications. Needless to say, the potential elements of waste and misallocation in such arrangements are great, and our past experience with government price supports in agriculture identify some of the pitfalls. Nevertheless, if the right combination of assurances and incentives can be contrived over the relevant time horizons, the social payoff may also be very high. Alternatively, subsidies via tax reductions or more direct means are worth considering in the case of the development of new technologies which are regarded as fulfilling certain peculiarly urgent social needs.

In some respects public policy toward technology may be much more effective if it addresses itself energetically to more modest goals and issues in addition to the big ones. We devote a large part of our concern and public dialogue to such large questions as fossil fuel vs. nuclear vs. solar energy, fission vs. fusion, etc. In our preoccupation with the big questions we neglect the fact that there are literally hundreds of things which we can do *now*, with our present technology, to reduce fuel expenditures. While no one of these may be very significant (actually some of them, even individually, *are* likely to be quite significant), cumulatively they could be of enormous importance. Getting people to respond to these possibilities for fuel savings requires a combination of forceful political leadership together with the introduction of incentives into our economic life to induce people to reduce fuel consumption—smaller cars with less "performance," more extensive use of home insulation materials, substitution of glass bottles for aluminum beer cans, etc. These and innumerable other possibilities for fuel savings are readily attainable within our present technology. What is required is a readiness to induce people to behave in energy-conserving ways by a more systematic exploitation of market place incentives, including in some cases a further strengthening of the incentives to socially-optimal behavior by a selective resort to taxes and subsidies. The obstacles here appear to be primarily political and not economic or technological. While one may reasonably anticipate eventual technological solutions to these problems, such solutions are likely to occur in the long run. In the short run we can take far more effective steps within the framework of our present technology.

To make a closely related point. The federal government in the energy field has, in the postwar years, poured a massive amount of money into the development of nuclear energy. I am not concerned for the moment to question the wisdom of that decision or the manner of its execution. I do, however, want to point out the unfortunate consequence of having placed all the energy eggs in a single basket—especially a source plagued with numerous uncertainties—and almost totally neglecting all other options. It is truly astonishing that we still know so little, in operational detail, about the technological

possibilities of energy alternatives such as shale oil and coal gasification and liquefaction, in view of America's abundant endowment of the appropriate resources. But, although the problem has recently arisen and presently confronts us most urgently in the energy field, I am anxious that my point not be confined to that context. The general point to be made, with respect to government technology policy, is that the national interest may require that we develop a capability for shifting to alternative sources of materials in various areas. The point is, to be sure, one which is more urgent in an international environment where access to vital raw materials is likely to be manipulated in response to either political considerations or the prospect of exploiting some monopolistic or oligopolistic advantage in world markets. Nevertheless, our interests in many areas dictate the wisdom of maintaining a capacity for flexible policy responses to changing conditions (This is especially true when the productive activity is one involving long lead times). Such flexibility in turn would require some minimum, ongoing research activity at the engineering and technological levels, and possibly even some support of pilot or demonstration plant projects in specific cases, in order to facilitate our capacity to move to alternative technologies more rapidly than appears to be possible at present. In a world of heightened political uncertainties it would seem to be doubly important that we should, as a matter of national policy, develop a capacity to reach specific goals via a diversity of routes.[28]

An implication of this discussion is that we have undervalued knowledge of a purely technological or engineering sort. I would like to suggest that this is at least partly due to the fact that our thinking in recent years has been dominated by an overly-simple view of the way useful technological knowledge is generated. Essentially this view states that technology can be sufficiently understood by regarding it as the application, to productive activities, of scientific knowledge. It is easy to understand how such a model has developed and come to dominate our thinking. Technological innovation in the twentieth century, and especially in the past 40 years or so, has thrown up an increasing number of instances where major breakthroughs—for example in electronics and chemistry—have been dependent upon scientific knowledge of fairly recent acquisition.

I do not want for a moment to challenge the notion that scientific knowledge is playing an increasingly-important role in the development of new technologies. I expect that dependence to become even greater in the years ahead, and I believe that the case for continued federal support of basic research, as opposed to the commercial development of new technologies, is overwhelmingly strong and should constitute a top priority. I do, however, want to insist that that model—of technology drawing upon and involving the application of recently-acquired scientific knowledge—is only a part of a much larger and

[28] The problems discussed in this paragraph are typically short-changed by the analytical apparatus of the economist, which presumes that profit-maximizing agents can move freely among a wide range of "known" alternative technologies. In fact, given the limited nature of detailed technical information, moving to alternative technologies which reflect different sources of materials or differing factor prices is far from the easy and effortless (i.e., costless) matter that it is made to appear to be. The smooth, continuous isoquants of microeconomic analysis scarcely ever have a counterpart in available knowledge. Especially in a high technology world, the acquisition of such knowledge is typically both costly and time-consuming. For further discussion, see Nathan Rosenberg, "Problems in the economist's conceptualization of technological innovation," *History of Political Economy*, No. 4, 1975.

more complex system of relationships and information flows. The point is a vital one because our preoccupation with the science-technology interface is leading us to pay insufficient attention to many other important aspects of the process of developing new and improved technology.

The question of the dependence of technology upon scientific knowledge is a conceptual minefield. It is essential, first of all, to distinguish between the total stock of scientific knowledge and recent *increments* to that stock. Furthermore, it does not add to conceptual clarity to define science so broadly that it becomes virtually coterminous with all of human knowledge. Once such a definition is accepted then, indeed, all technological innovation must involve the application of science. Such propositions then become simply uninteresting. If science is defined, as it ought to be, in a more restrictive sense, it is much more difficult to show that technological changes are tied to *current or recent* increments to that stock of scientific knowledge. Failure to make such distinctions frequently leads to platitudinous or merely tautological assertions about the relations between science and technological change. A more useful perspective is one which recognizes that there are different realms of knowledge—including the scientific and the technological.

One of the problems created by the crude identification of science with all knowledge is that it often leads to the incorrect assumption that we already possess the essential knowledge to achieve certain goals and that all that remains to be done is to go out and *apply* that knowledge. In fact, often the knowledge itself—which is technological knowledge—simply does not exist. Many American foreign aid programs after World War II, which required for their success the transfer of technological knowledge, foundered over this issue. Often we did not possess the appropriate knowledge in the first place, and therefore we were incapable of transferring it. Such difficulties were often compounded by the failure to recognize the location-specific nature of much technological knowledge pertaining to agriculture. Fortunately this range of problems is now being dealt with more successfully by the establishment in recent years of regional and national agricultural research stations throughout the world.

What has to be recognized is that much of the technological realm remains, to a considerable extent, "self-contained" in the sense that it exploits knowledge which has been produced *within* that realm and not imported from the scientific world. Such knowledge is often a byproduct of the productive process itself, in the sense that participation in that process generates knowledge about productive relationships and new design possibilities which are unlikely to be generated elsewhere. Furthermore, much of the work of the specialized engineering disciplines is of a kind which cannot be adequately subsumed under the category of applying pre-existing scientific knowledge. Indeed, it may be asserted that it is a major activity of the engineering profession to develop workable techniques which specifically *bypass* the need for scientific knowledge—for the excellent reason that the appropriate scientific knowledge often simply does not exist.

Much of the most important work of engineers has involved the design and development of products with certain performance specifications and without the guidance of systematized scientific knowl-

edge. In aerodynamics and fluid mechanics, for example, engineers have routinely produced information sufficient for a safe and workable solution to some technical problem long before scientific understanding was achieved. Technological progress on the steam turbine has shapes by empirical means, well in advance of scientific understanding. Similarly, over the years such important pieces of "hardware" as ship hulls and propellers, water turbines, airplane fuselages, internal combustion and diesel engines have all achieved their optimal design shapes by empirical means, well in advance of sceintific understanding. Indeed, just as the attempt to understand the factors determining the performance of the steam engine historically gave rise to the laws of thermodynamics, so has the attempt to understand the principles determining the operation of *already-existing* technology given rise to the development of further new scientific knowledge. Thus the relation between the realms of science and technology is not a simple and linear one of causation, but includes much more intricate loops and feedbacks than is generally recognized.[29]

Moreover, scientific progress is and always has been highly dependent upon technological improvements which enhance our capacity to observe and to experiment. This is particularly true in the realm of instrumentation. Our present knowledge of the natural world, ranging from microbiology on the one hand to cosmology on the other, would have been inconceivable without the microscope and telescope. Further improvement in these "old" technologies holds out the promise of fundamental scientific breakthroughs in the years immediately ahead. Superior instrumentation—electronic microscopy, computers and perhaps new techniques such as L.E.E.D. (Low Energy Electron Diffraction)—is bringing us within reach of a genuinely predictive biology and a theoretical chemistry of large molecules. The imminent placing of powerful telescopes in outer space will almost certainly lead to fundamental increases in our knowledge of the universe, as these new observational possibilities lead to a resolution of conflicting hypotheses or perhaps to totally new ones with respect to quasars, "black holes," the red shift, and the theory of gravitation itself.

Another basic difficulty in understanding the way technological change contributes to productivity growth is that we are all but unaware of some of the most important routes by which this contribution takes place. The difficulty in perception seems to be due to a variety of causes: to the small size of individual improvements, to a frequent preoccupation with what is *technologically* spectacular rather than *economically* significant, and to the inevitable, related

[29] This is a big subject which cannot be pursued here. It is worth insisting, however, that even in some of the most advanced of our high technology industries, basic research received its stimulus from already-existing technologies. Thus, after discussing various developments in post-war physics—nuclear physics, solid-state physics, gas-discharge physics, etc.—Harvey Brooks points out: "It seems to me noteworthy, in this history, that, contrary to some of the mythology concerning the relationship between basic and applied science, the big stimulus to research in an area followed rather than preceded an invention. The basic science was motivated by the necessity to generate ancillary technology to feed the development and exploitation of an initial invention, rather than vice versa. Of course, this search for ancillary technology often generated new inventions in unexpected directions, and the fact that it was conducted in a relatively free and inner-directed environment helped increase the number of unforeseen by-products. Nevertheless, we must note that in almost every case a technological invention preceded much of the explosive growth in many subfields of physics." Harvey Brooks, "Physics and the Policy," *Science*, April 26, 1968, p. 399. See also M. Gibbons and C. Johnson, "Relationship between Science and Technology," *Nature*, July 11, 1970, which further underlines the complexity of the science-technology interactions in the case of the development of the transistor—a case which is usually assumed to be a classic and unambiguous example of modern technology building upon established scientific knowledge.

difficulty which an outsider has in attempting to appreciate the significance of alterations within highly complex and elaborately differentiated technologies, especially when these alterations are, individually, not very large.[30]

It is useful here to think in terms of the life cycle of individual innovations. Major improvements in productivity often continue to come long after the initial innovation as the product goes through innumerable minor modifications and alterations in design to meet the needs of specialized users. Widely used products like the electric motor, the machine tool or the transistor experience a proliferation of changes as they are adapted to the varying range of needs of ultimate users. Consumer durables have typically gone through parallel experiences with especial emphasis upon expanding the quality range in catering to different income categories. Such modifications are achieved by unspectacular design and engineering activities, but they constitute the substance of much productivity improvement and increased consumer well-being in industrial economies.

Much of the technological change which goes on in an advanced industrial economy is, therefore, if not invisible, at least of a low visibility sort. It includes a flow of rather prosaic improvements in such areas as materials handling,[31] the redesign of productive equipment and final products for greater convenience, and measures which reduce maintenance and repair costs, as in modular machinery design.[32] In metalworking and introduction of new and harder material in the cutting edges of tools has made possible a steady acceleration in the pace of work. In the steel industry the continued reduction in fuel requirements per ton of output, a trend which can be traced well back into the 19th century, continues unabated. The cumulative impact of these individually small changes has, again, been very substantial. Whereas it required almost 1900 pounds of coke to produce a ton of pig iron in 1949, by 1968 it required only 1200 pounds.[33] Similarly in electric power generation, where the long-term rate of growth of total factor productivity has been higher than any other American industry,[34] the slow, cumulative improvements in the efficiency of centralized thermal power plants have generated enormous long-term increases in fuel economy.

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[30] As Carter and Williams aptly point out, "The examples of the application of science and technology to industry which come most easily to mind are the revolutionary changes, the basically new products—penicillin, nylon, Terylene, television sets, the gas turbine, the electronic computer. Changes in processes—high draft spinning, shell moulding, palletization—tend to be less well known, unless they are embodied in some notable machine. It is things, rather than processes, which catch the public eye. But for every radical innovation which thus rises to fame, there are tens of thousands of minor improvements in products and processes, which (though individually not a complete break with the past) may over a period of years create something quite new. Consider, for instance, the evolution of the piston-engined aircraft from the first small, slow and unsafe planes to the Super-Constellation, capable of maintaining regular and fast services over thousands of miles . . . (T)he closer one looks at industry, the more plain it becomes that many great changes are the product of countless steps of evolutionary development." C. F. Carter and B. R. Williams, *Industry and Technical Progress*, Oxford University Press, 1957, pp. 13–14. See also Nathan Rosenberg, *Perspectives on Technology*, *op. cit.*, Chapters 4 and 11.

[31] For example, in the construction industry "There are a plethora of materials handling improvements. They range from hoists of all types, to conveyors, to higher line speeds, to powered concrete buggies, to more handleable packages on the part of suppliers. These improvements have been continuous and probably no single change is individually significant . . ." A. D. Little, Inc., *Patterns and Problems of Technical Innovation in American Industry*, Report to National Science Foundation, September 1963, p. 132.

[32] Innumerable such examples may be found in U.S. Dept. of Labor (B.L.S.) *Technological Trends in 36 Major American Industries*, 1964, and *Technological Trends in Major American Industries*, 1966, Bulletin No. 1474.

[33] Bureau of Mines, Dept. of Interior, *Mineral Facts and Problems*, 1970, p. 40.

[34] John Kendrick, *Productivity Trends in the United States*, New York, Princeton University Press, 1961, pp. 136–37.

A stream of minor plant improvements, including the steady rise in operating temperatures and pressures made possible by metallurgical improvements such as new alloy steels and the increasing sophistication of boiler design and resulting increased capacity, have sharply raised energy output per unit of fuel. The long-term cumulative importance of such individually small improvements may be indicated as follows: It required almost seven pounds of coal to generate a kilowatt-hour of electricity in 1900, but the same amount of electricity could be generated by less than nine-tenths of a pound of coal in the 1960s.[35] But even this figure understates the full improvement in the utilization of energy sources.

> During the 50-year period 1907–1957 reduction of the total energy required or lost in coal mining, in moving the coal from mine to point of utilization, in converting to electrical energy, in delivering the electric energy to consumers, and in converting electric energy to end uses have increased by well over 10 times the energy needs supplied by a ton of coal as a natural resource.[36]

In the construction industry, often regarded as a stronghold of traditionalism and conservatism, there have been innumerable minor changes of great cumulative significance, but it may be that the organizational changes have been even more significant than the purely technological ones.

> During the last thirty years, the U.S. building industry has undergone a radical change of character. Project and corporate size has increased greatly. Equipment, materials, design and planning practices, are in many ways of different than those employed before the Depression. Nevertheless, while the industry as a whole has undergone major change, this change has proceeded in the small segments of the industry through many small increments. There has been no radical change, of great technical and economic significance, which is associated with a single invention or family of inventions. Nothing is to the building industry as synthetic fibers and finishes are to textiles or as numerical controls are to machine tools. In the building industry, change has been evolutionary—like the many small process changes accounting for increased productivity in machine tools and textiles—and much of the most important change cannot be described as technical at all. It has had to do, rather, with methods of managing and organizing the building process.[37]

A more general source of small, low-visibility innovations of great cumulative significance has been the multitude of ways in which maintenance and service requirements for capital goods have been reduced and the useful life of capital goods prolonged. The substitution of new materials—e.g., aluminum, plastics, and a wide range of alloys—for old ones, and improved techniques of friction reduction, have led to a considerable extension of the useful life of all kinds of capital equipment. Such improvements are rarely visible to the non-specialist.

The significance of small cumulative improvements is further underlined by two valuable studies. In one, Samuel Hollander's study of the du Pont rayon plants, the author attempted to determine the ex-

[35] Hans Landsberg and Sam H. Schurr, *Energy in the United States*, New York, Random House, 1968, pp. 60–61.

[36] *Historical Statistics of the United States*, p. 501. See also William Hughes, "Scale Frontiers in Electric Power," in William Capron (ed.), *Technological Change in Regulated Industries*, The Brookings Institution, Washington, D.C., 1971.

[37] A. D. Little, Inc., *Patterns and Problems, op. cit.*, p. 119. The availability of superior materials has been particularly important to construction. "Improvements in construction materials make possible more efficient utilization. Paints, for example, require less on-site preparation and less effort in their application. Adhesives are being more widely used to save time and reduce wall costs. Plastics offer the advantage of ease of handling and ability to be molded to extremely close tolerances. The development of high-strength and rust-retardant steels allows construction in which the steel is exposed to the weather. Labor and other cost savings of 25 percent can be realized by the use of prestressed concrete beams in place of structural steel in some areas. Prestressed concrete also makes possible wide spans where column-free construction is desirable. Brick construction has benefited by the development of high-strength mortar." U.S. Dept. of Labor (*Office of Productivity and Technological Developments*), *Technological Trends in 36 Major American Industries, op. cit.*, pp. 12–15.

tent to which observed reductions in unit costs of production at particular plants were the result of identifiable changes in the techniques of production. Hollander's findings are of great interest in the present context. Unit costs declined strikingly in the du Pont plants which he studied. Furthermore, he finds that the contribution of technical change in accounting for these reductions was "of overwhelming importance," [38] And, most significant for our present purposes, is his finding that the cumulative effect of minor technical changes upon cost reduction was actually greater than the effect of major technical change.[39]

Hollander is, of course, aware that there is an interdependence between minor and major technical changes, and that "without some preceding major change the potential stream of minor changes will be exhausted." [40] Nevertheless, his findings lend powerful support to the view that the economic importance of minor technical improvements has been vastly underestimated.

Hollander's findings for rayon are closely paralleled by those of Enos in his study of technological change in petroleum refining. Enos studied the introduction of four major new processes in petroleum refining: thermal cracking, polymerization, catalytic cracking, and catalytic reforming. In measuring the benefits for each new process he distinguished between the "alpha phase"—or cost reductions which occur when the new process is introduced—and the "beta phase"—or cost reductions which flowed from the later improvements in the new process. Enos found that the average annual cost reductions which were generated by the beta phase of each of these innovations considerably exceeded the average annual cost reductions which were generated by the alpha phase (4.5 percent as compared to 1.5 percent). On this basis he asserted that "The evidence from the petroleum refining industry indicates that improving a process contributes even more to technological progress than does its initial development." [41]

Finally, along these lines, there is much evidence that this sort of technological improvement characterizes the most advanced of the high technology sectors. Kenneth Knight, in summarizing his work on the computer industry, asserts that ". . . most of the developments in general-purpose digital computers resulted from small, undetectable improvements, but when they were combined they produced the fantastic advances that have occurred since 1940." [42]

The accurate perception of the economic benefits of technological innovation is further obscured by the difficulties involved in completely identifying the growth in productivity associated with a given innovation. Specifically, many of the benefits of increased productivity flowing from an innovation are captured in industries other than the one in which the innovation was made. As a result, a full accounting should, in principle, encompass all of these inter-industry relationships. In practice it is difficult to identify, much less measure, these benefits. Partly this is due to the fact that industrial development

[38] Samuel Hollander, *The Sources of Increased Efficiency: The Study of du Pont Rayon Plants*, M.I.T. Press, 1965, pp. 192–93.
[39] *Ibid.*, p. 196.
[40] *Ibid.*, p. 205.
[41] John Enos, "A Measure of the Rate of Technological Progress in the Petroleum Refining Industry," *Journal of Industrial Economics*, June 1958, p. 180. Enos' findings are presented in much greater detail in his book, *Petroleum, Progress and Profits*, M.I.T. Press, Cambridge, Mass., 1962.
[42] Kenneth Knight, "A Descriptive Model of the Intra-firm Innovation Process," *Journal of Business*, October 1967, p. 493.

under a dynamic technology leads to wholly new patterns of specialization both by firm and by industry, so that it is impossible to compartmentalize the consequences of technological innovation within any set of established industrial boundaries.

One component of the changing patterns of industrial specialization is the emergence of specialized firms and industries which produce no final product at all, but only capital goods. Much of the technological change of the past two centuries or so has been generated by these specialist firms. The main beneficiaries of technological change in these capital goods industries are, in the first instance, the buyers and users of these capital goods in other industries, but the total benefits are often very widely diffused in an economy of increasingly specialized productive units and high rates of inter-industry purchases.

The ways in which technological changes coming from one industry constitute sources of technological progress and productivity growth in other industries defy easy summary or categorization. In some cases the relationships have evolved over a considerable period of time, so that relatively stable relationships have emerged between an industry and its supplier of capital goods. Equipment makers are a major source of technological change in many industries. Merton Peck has shown, in a rigorous way, the decisive importance of equipment makers to technological change in the aluminum industry.[43] On many occasions the availability of new and superior metals has played a major role in bringing performance and productivity improvements to a wide range of industries—in machine tools, electric power generation, jet engines and transistors, among others. The availability of plastics has had wide-ranging effects in raising productivity in many sectors of the economy, including "old" industries. For example, although plastics are more expensive than wood per unit of weight, they are much easier to shape and to mold.

As a result, the use of plastics in the furniture industry has made possible very significant increases in labor productivity. Since the 1930's the building industry has been the recipient of numerous new plastics products which have found a wide range of uses—not the least of which has been cheap plastic sheeting which made possible an extension of the construction year by providing protection on the building site against inclement weather. The sharp increase in the utilization of commercial fertilizer inputs in American agriculture can be entirely explained by the decline in fertilizer prices. This decline, in turn, was to a considerable extent the result of technological change in the fertilizer industry.[44] Agriculture has in fact become highly de-

[43] Merton J. Peck, "Inventions in the Postwar American Aluminum Industry," in *The Rate and Direction of Inventive Activity, op. cit.*, pp. 279–298. See especially Table 1, p. 285.

[44] See Zvi Griliches, "The Demand for Fertilizer: An Economic Interpretation of a Technical Change," *Journal of Farm Economics*, August 1958, pp. 591–606. According to Griliches, "The use of fertilizers in U.S. agriculture, which has more than quadrupled since 1940, was greatly stimulated by the approximate halving of fertilizer prices (from their pre-World War II levels) relative to both farm product and other input prices. This fall was due to a series of developments in the nonfarm sector: the decline in the real price of energy, a main input in the production of synthetic nitrogen; the breakup of the nitrogen cartel as the result of government construction of new nitrogen plants during the war and their subsequent resale to new entrants into the industry; and the savings in transportation and handling costs, both at the manufacturing and retail levels, as the result of a continuous shift toward stronger mixtures. Similarly, the substitution of mechanical power for human labor was induced by the rising price of labor, which was due to the higher wages in the rest of the economy, and the resulting out-migration of farmers, and the decline in the real price of machinery, which was mainly the result of the decline in the real price of horsepower with the development of higher-compression engines." Zvi Griliches, "Productivity and Technology," under "Agriculture," *International Encyclopedia of the Social Sciences*, vol. 1, p. 242.

pendent upon the purchase of inputs from the nonfarm sectors—not only fertilizer but herbicides, insecticides, machinery and equipment, fuel, etc.

Often, however, an innovation from outside will not merely reduce the price of the product in the receiving industry, but make possible wholly new or drastically improved products or processes. In such circumstances it becomes extremely difficult even to suggest reasonable measures of the productivity impact of triggering innovations because such innovations, in effect, open the door for entirely new economic opportunities and become the basis for extensive industrial expansion elsewhere. For example, the chemical industry has exercised a massive effect upon textiles through the introduction of an entirely new class of materials—synthetic fibers. The great popularity of these new materials, especially in clothing, is attributable to the possibility for introducing specific desirable characteristics into the final product, often as a result of blending (including blending with natural fibers). Thus, materials used in clothing can now be designed for lightness, greater strength, ease of laundering, fast drying, crease retention, etc.

Technological change in the chemicals industry has exercised a similar triggering function in other industries than textiles. Thermochemical (as well as electrothermal) developments have resulted in the introduction of an expanded range of new metals and new alloying materials. Such techniques have made possible the reduction of ores of high-melting metals such as manganese, chromium, tungsten and, most important, aluminum. In the case of the electrical industry, the chemicals industry played a critical role through the provision of refractory materials, insulators, lubricants, and coatings, and provided metals of a high degree of purity for use in conductors. The profound effects of chemicals innovations have had a relatively limited visibility because of the intermediate good nature of most chemical products.

The electronics industry in recent years has been exercising triggering effects which have been, in many respects, closely parallel to the experience of chemicals, particularly with respect to the wide range of product innovations which have been developed upon the transistor. Here again one cannot summarize the economic importance of the transistor in terms of volume of sales or cost reductions. For the transistor has made possible the introduction of entirely new products, it has dramatically improved the performance of old products and processes, and it has played a less direct but nevertheless profound role in many parts of the economy. Mere reference to the impact of the computer in the last fifteen years will suffice to suggest the nature and scope of these derivative innovations.

The transmission of technological change from one sector of the economy to another through the sale of intermediate output has important implications for our understanding of the process of productivity growth. The contrast often drawn between sectors which are regarded as technologically progressive and sectors which are regarded as technologically stagnant may be badly overstated and misleading. As Schmookler has pointed out:

> . . . the greater part of the output of most industries is sold to other industries, not to final consumers. The chemical and electrical industries are like most others in this respect. In consequence, most chemical, electrical, and electronic products constitute improvements in the inputs of other industries. For this reason, contrasts between the "progressiveness" of the former with the "un-

progressiveness" of the latter are likely to be misleading. The ability of the former to market new products depends precisely on the "progressiveness" of their customers. Moreover, since improvements in the product technology of the former usually improve the production technology of one or more other industries, contrasts between the susceptibility of the technologies of the former to improvement and the lack of such susceptibiltiy in the technologies of other industries are commonly overdrawn. It would perhaps be more useful to contrast the ripeness of the product technology of the new, science- and engineering-based industries with the ripeness of the product technologies of other industries whose products serve the same purposes. For example, the meaning of a contrast between the potentialities of synthetic fiber technology with those of natural fiber technology is obvious. On the other hand, a contrast between, say, the possibilities of coal tar dye technology and those of the textile industry in the nineteenth century needs more explaining than such contrasts usually get. The high degree of interdependence of the industries in a modern economy may mean that the net genuine superiority in the improvement possibilities of one industry's total technology over another's may easily be less than one might infer from simple inter-industry differences in, say, the ratio of each industry's patents to its value added, because the best way to improve an industry's technology is often to improve the inputs it buys from other industries.[45]

It is essential to appreciate that a few industries may be responsible for generating a vastly disproportionate amount of the total technological change in the economy. Government policy directed at stimulating technological change generally, for example, or for stimulating the output of certain categories of goods or services, will need to be based upon the clearest possible understanding of the interindustry relationships which have been discussed here. Enlightened government policy in this area will require sophisticated knowledge of these technological interdependencies. Similarly, an examination of the pattern of R&D expenditures by industry may be grossly misleading in the sense that technological change and productivity growth in an industry need bear no direct relationship to R&D expenditures in that industry. For example, although electrical power generation has one of the very highest rates of technological change and productivity growth of any sector of the economy, the industry has had virtually no R&D expenditures of its own. Rather, technological change in electric power generation has flowed from the research expenditures of the equipment industry, the metallurgical industries, and various other federally-supported research projects. Thus, even though only a few industries are research-intensive, the inter-industry flow of new materials, components and equipment may generate widespread product improvement and cost reduction throughout broad sectors of the economy. This has clearly been the case in the past among a small group of producer goods industries—machine tools, chemicals, electrical and electronic equipment, and metallurgy. Industrial purchasers of such producer goods experienced considerable product and process improvement without necessarily undertaking any research expenditure of their own. Such inter-industry flow of technology is one of the most distinctive characteristics of the contemporary American economy. Indeed. Indeed, it might even be more appropriate to say that such technology flows have radically reshaped industrial boundary lines, and that we still talk of "inter-industry" flows because we are working with an outmoded concept of an industry. As one study has pointed out:

Some industries and companies have gotten bigger at the expense of others. But, more to the point, traditional industries have changed their form. Any consideration of the textile industry would be artificial which did not include the

[45] Schmookler, *op. cit.*, pp. 174–175.

chemical, plastics, and paper industries. Consideration of the machine tool industry must now take into account the aerospace, precision casting, forging, and plastics forming industries. These industries are now complex mixtures of companies from a variety of SIC categories, some functioning as suppliers to the traditional industry, some competing with it for end-use functions and markets. "The industry" can no longer be defined as a set of companies who share certain methods of production and product-properties; it must be defined as a set of companies, interconnected as suppliers and market, committed to diverse processes and products, but overlapping in the end-use functions they fill. We can talk about the "shelter" industry and the "materials forming" industry, but we cannot make the assumptions of coherence, similarity and uniformity of view which we could formerly make in speaking of "builders" or "machine tool manufacturers". Similarly, companies are coming to be less devoted to a single family of products and manufacturing methods, and more a diverse conglomerate of manufacturing enterprises, stationed around a central staff and bank, and to some extent overlapping in the markets and functions they serve. These changes are part and parcel of the process of innovation by invasion.[46]

Conclusion

The essential point to be emphasized here is that technological change and its associated productivity improvements enter the economy, as I have tried to indicate, through many doors and take a wide variety of different forms. Moreover, the location of these doors seems to shift periodically, so that any rigid mapping of the most significant relationships is bound to become outmoded over time—and not very long periods of time at that. It is of basic importance to the formulation of policy to recognize explicitly this diversity of routes and forms by which technological changes lead to improvements in productivity.[47] Unlike basic research, for which there is a strong and compelling case for government support, technological innovation can ordinarily rely much more directly and successfully upon the commercial incentives of the market place. Government can exercise an important influence by policies directed toward the assurance of high levels of economic activity but, in general, it can contribute more by providing a suitable environment for the operation of market incentives than by specific measures to aid particular industries or interest groups.

Many of the things which contribute to the overall good health of the economy, and which are therefore desirable for other reasons, also contribute to the more effective exploitation of new technological opportunities. I include here the reduction of barriers to entry and resource mobility, legal and institutional changes which more effectively link individual incentives with the attainment of larger collective goals (including the modification or elimination of those government regulations which are clearly counterproductive) and the achievement of higher overall rates of employment and economic activity than we have experienced in recent years.

Finally, we need to discard as a chimera the view that America should attempt to maintain an across-the-board technological superiority. Such a goal is, I submit, unrealistic and unattainable, but the mere *pursuit* of such a goal is likely to be fraught with dangerous con-

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[46] A. D. Little, Inc., *Patterns and Prospects, op. cit.*, p. 181.

[47] This diversity, which is closely linked to the highly heterogeneous nature of contemporary American industry and its varied technologies, is probably the main reason why it is so difficult to say something general about the effects of the patent system. If one thing is clear, it is that the patent system exercises very different kinds of effects in different industries. It is a highly important device in, say, the pharmaceutical industry but it is much less important in, say, the automobile industry. Any serious evaluation of its effects, or of the probable consequences of specific alterations in the patent law, will have to await a series of careful case studies of individual industries.

sequences. There is a fundamental difference between technological success and commercial success. Indeed, I believe that America's success in the high technology areas has been due in no small measure to the exercise, by private industry, of a shrewd commercial judgment concerning adoption decisions—i.e., deciding when a new technology has reached the point of commercial feasibility and profitability. The attempt to push a new technology too quickly into commercial use, especially with the encouragement of public funds, is likely to be highly wasteful in the long run. It is worth recalling that, in the early 1950s, the British introduced commercial jet service (Comet I) two years before the Americans began the development of a jet airliner. As we now know, the Americans eventually won out and have dominated the international aircraft market ever since. Boeing and Douglas made the correct commercial decision in choosing to postpone adoption, and derived the great benefit of being able, somewhat later, to design a commercial airliner around more powerful engines which offered great economic advantages, while the British de Havilland firm suffered the penalty of premature adoption of a fast-improving technology.[48]

One of the great—and perhaps least celebrated—virtues of a capitalist society is that capitalists are exceedingly good at minimizing their losses, at unsentimentally cutting off expenditures for projects when the prospects for commercial exploitation appear sufficiently weak or dubious. Recent experience strongly suggests that projects receiving sizeable government support are likely to suffer from an entirely different dynamic, one where it becomes increasingly difficult to cut off expenditures upon projects to which a government and its bureaucracy have already made a heavy commitment of finance and prestige.[49] It is characteristic of such projects that firm and essentially irreversible large-scale financial commitments are made at a very early stage when the technical knowledge necessary for intelligent decisions is necessarily fragmentary, and when therefore the level of uncertainty is still very high. I would not be entirely surprised if, in ten years' time, this propensity were to be referred to as the "Concorde Syndrome." In the meantime I would suggest that we should remain highly skeptical concerning the commitment of sizeable public funds to the final stages of commercial exploitation of a new technology. Although there is a persuasive case to be made for government support of basic research and for exploratory technological development in some specific areas, such a case has little pertinence to decisions concerning the final development and commercial exploitation of new or improved products.

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[48] This penalty included tragic accidents due to the phenomenon, still not understood at the time, of metal fatigue. For a more general discussion of the problems involved in the adoption decision of rapidly-changing technologies, see Nathan Rosenberg, "On Technological Expectations," *Economic Journal*, September 1976.

[49] See George Eads and Richard Nelson, "Government Support of Advanced Civilian Technology," *Public Policy*, 1971, pp. 405–427, for a cogent and incisive discussion of some of the relevant issues.

TECHNOLOGICAL CHANGE AND FUTURE GROWTH: ISSUES AND OPPORTUNITIES

By JOSEPH F. COATES * **

SUMMARY

Over the next three decades we may anticipate major technological advances and changes in American society in the area of electronics, automation, information handling, food, and biological manipulations, as well as in the more commonplace areas of industry, commerce, and domestic devices. Dominant elements driving these changes are fundamental shifts in the availability of energy and materials, which will stimulate major innovation in substitutions, extended service life, and easier maintainability; and the increasing role of science as a wellspring of new technologies. Furthermore, the movement of U.S. society into a post-industrial society with its emphasis on knowledge based industries will stimulate major shifts in the nature and location of work, land use, and information-associated technologies. This will be accompanied by a flourishing of social, institutional, and psychological technologies.

Market forces will play a dominant role in the realization of these new technological developments. In addition to these forces, technological needs and opportunities will arise which lie outside the market system, such as developments with regard to geophysical manipulation, earthquake control, and weather modification.

The principal role of government in assuring continuing benefits from technology is guiding the socially effective interplay of the basic variables: land, labor, capital, resource availability and knowldege. To be socially useful, the interplay must be future-oriented, flexible, and information driven. One specific role for government is setting reliable boundary conditions on private and public endeavors with some clarity and incisiveness to permit market and non-market forces to operate. Put differently, a principal role for government is the more effective management of uncertainties with regard to future potential opportunities and risks in order to encourage new and needed developments and innovations.

A principal limitation on technological and scientific decisionmaking is the inadequacy of knowledge gathered and organized for the purpose of illuminating public policy. Meeting these information needs is a second specific role for government. Since most information is collected for other purposes, modifications which explicitly generate and collect policy-related information would effect a major improvement in public and private decisionmaking.

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**The material in this paper is the responsibility of the author and does not represent the position of any government agency or the U.S. Congress.

The wider practice of the concept of technology assessment as a means to better understand options, alternatives, and consequences for technology should be encouraged in and out of government.

Many major regulatory agencies of government reflect needs and problems decades old which are no longer of primary importance. A third specific role for government in guiding technology, the reform of the regulatory agencies through their restructuring, offers major opportunities for more effective management of technology. Primary candidates for this specific role of government include agencies regulating communications, drugs, banking, securities, energy, health care, transportation, and marine and oceanographic affairs.

The fourth major role for government, research and development, should be driven by several convergent factors. There are opportunities for new and expanded technological developments with regard to: (*a*) The wiring of metropolitan and rural areas for fuller telecommunications; (*b*) the introduction of major new energy sources such as solar, geothermal, and ocean technologies; (*c*) the reformulation of education technologies, welfare, and health delivery systems; and (*d*) the reconstruction of cities and other habitats. Furthermore, the economically mature society implies not less but different technology emphasizing: social and biological as well as physical technology; personal improvement and fulfillment, and accomplishing more with less. There also are numerous problems of a high-growth society such as the propensity to maximize bureaucratic efficiency at the expense of social effectiveness; alienation of workers; adverse effects of excessive size and integration; societal needs not accommodated by market forces, and the negative side effects of technology. Each of these clusters of problems and opportunities could be profoundly influenced by research and experimentation.

I. Introduction

Technology is universally recognized as a crucial, if not the dominant, consideration in the present and future economy of the United States. This essay explores the basic factors influencing future technological developments and highlights their implications for the economy, the society, and public policy.

The profound stimulus of technological change for economic growth is so well known and documented that it will not be discussed here. Perhaps more important to note is that at least four basic factors—land, labor, capital, and resource availability—limit the economy's choices and in turn limit and influence the technological choices appropriate to meet the market demands of the private economy and the non-market or quasi-market demands of government.

In the United States the relationship among these basic factor inputs and determinants of technology is undergoing major change. The increase in the cost of energy is perhaps the sharpest recent change. The longer-term shifts in general resource availability have been steadily and continually accommodated by the economy and this adjustment will continue. While resources have gotten relatively cheaper over the long run, we may be reaching the point where resource depletion and increasing worldwide demands will reverse that trend. The limits of land availability have given rise to a growing discussion of competitive land uses. For western land water exploitation, farming, cattle, and urban development are in competition with recreation and re-

source development. Around the fringes of our great cities the steady takeover of high quality farmland for urban development is now controversial. And finally, the changes in labor force development can be seen in several ways. Among the most important changes are in the quality of labor, the change in its orientation toward work, the passage of the large postwar baby population into the work force and the expected subsequent rise in average worker age, and the entry of minority groups and women into the labor force in greater numbers with greater demands for upward mobility.

A fifth key element must be added to the traditional factors of land, labor, capital, and resources. This factor is knowledge. Knowledge, particularly from science, is expanding and affecting society so profoundly as to merit independent recognition.

One can anticipate that these forces, in striking a new balance, will initiate continuing waves of technological change. In much the same way that charcoal was replaced by coal in the British iron and steel industry, in the way in which synthetic rubber arose to replace scarce natural rubber in World War II, and as the Haber process for ammonia was devised to relieve the shortage of natural nitrogen fertilizers in Germany in World War I, one can anticipate continuing and steady initiation of major new technologies. Since new technologies will be a primary means of accommodating to the changing balance of energy, materials, labor, and land, these changes can be regarded as stimulants to invention and innovation.

Guiding the interplay of these five variables will be a major function of government over the next three decades. The principal implications for government in this regard fall into four major areas:

The management of risk and uncertainty in order to promote useful techno-economic change.

The generation, distribution, and use of knowledge, especially knowledge for policy planning and programs.

The institutionalization of technology and its regulatory and control institutions.

The support of research and development.

But there is more than that to technological change in America.

There is almost nothing that Americans touch, hear, smell, eat, live with, work with, or use for pleasure and recreation which has not either been generated by or drastically transformed by science and technology within the past 50 to 75 years. The intimacy with and dependence on technological change in our personal and collective lives is likely to continue to flourish over the next few decades. The likely and potential technological developments leading to new capabilities, new products, new industries, and new social functions are so many and diverse that it is difficult to do more than hint at their widespread impact.

Major new technologies will almost inevitably develop in electronics, automation, information handling, agriculture, food, biological manipulation, in social, psychological, and institutional technologies, water management, oceanography and space. Attempts to anticipate probable specific developments in these fields are likely to fall far short of future reality for at least four reasons. First, fundamental new discoveries in science will spawn vast new capabilities. Second, many new developments flow out of synergistic developments among technologies. These are difficult to foresee. Third, while there is a

tendency to be overly optimistic about what might be accomplished in the short run, longer-run projections covering several decades tend to be too conservative about what might be achieved and about the social changes deriving from those achievements. Fourth, the presence or absence of effective government policies will have a primary effect on choices among the alternative technological futures before us.

One useful approach to technological policy is in terms of the interplay between the basic characteristics of technology in general, and the principal social issues bearing upon it. In the next section several such issues influencing technology and choices in technology policy will be discussed. Section III offers a number of basic propositions to illustrate the central role of technology and science in the contemporary world. Those propositions attempt to provide a conceptual framework for understanding America's technology and the public policy issues surrounding it. From each proposition, some implications for new technology and public policy will be derived. The final section draws together policy recommendations for shaping government's role in dealing with technological opportunities and problems.

II. Some Factors Influencing Future Technological Development

In this section, we will consider some key economic and social forces influencing future technological developments. These forces derive, in part, from the consequences of our traditional high rates of economic growth and from the evolution of the U.S. into a post-industrial society. Others stem from the fundamental shift in availability and prices of raw materials and energy, from changing social values, from new markets and from the role of government intervention.

A. *Some Problems of the High Economic Growth Society*

Features of our laws, institutions, and culture that are outmoded, inefficient, or pose obstacles to human satisfaction and progress must be judiciously but steadily designed out of the system. That redesign implies, as a minimum, foresight, analysis, and coordinated action, i.e., planning. While major structural problems exist in all economies, especially low-growth, less developed economies, there are some more characteristic of the economically advanced nations. From the point of view of this essay, the problems of our high-growth economy have implications for present technology and the introduction of new technologies over the next several decades.

1. EFFICIENCY OFTEN IS AT THE EXPENSE OF EFFECTIVENESS

Adequate attention to the overall social effectiveness of many public- and private-sector programs and products is often obscured by organizational behavior which substitutes criteria of bureaucratic efficiency for measures of social performance. Optimization on readily quantifiable, bureaucratic efficiency criteria and the associated confusion with social effectiveness criteria often generates negative externalities. An example is the $29.95 toaster which requires $6.50 and two hours of the owner's time to replace a 35-cent part. Inattention to such externalities, of course, is a common reason for allowing these criteria shifts to occur. Because internal bureaucratic or economic efficiency or some putative

measure of it is almost always easier than effectiveness to measure or quantify, efficiency tends to become the surrogate for effectiveness. Eventually, the surrogate effectiveness criterion acquires a life of its own. This relationship between social effectiveness and organizational efficiency often goes as follows:

Task	Social effectiveness criterion	Institutionally substituted efficiency measures
Research and development	Impacts on economy/society	Bureaucratic budget growth.
Welfare	Extent to which people are helped	Cases closed.
Food stamps	Improved nutritional status	Numbers of people assisted.
War	Relation to political objectives	Body count.

Analogous displacements of social effectiveness by efficiency criteria occur throughout the market system in which consumer goods are often made with limited durability to save relatively small marginal initial costs. This situation is either unrecognized by the consumer, hidden from him, or not structured out of the market by the regulatory apparatus. A minimum role for government in these cases is to see that the relevant information is available to the consumer, for example, requiring energy-consumption and repair costs on consumer devices.

As we move to more explicit use of social effectiveness criteria one can expect major changes in technology and technology-supporting systems, notably R&D. Particularly promising areas for the introduction of social effectiveness criteria are in social technologies in health, education, training, welfare, insurance, and services. These areas are open to new, explicit criteria because they deal to a large extent with externalities and often incur externalities.

Factors promoting, but not guaranteeing, a move to effectiveness criteria include the growing concern for externalities and social cost, the movement within government toward greater accountability, and a generally longer planning-time horizon in government and business. There is also the consumer movement which is focusing attention on total lifetime costs of goods, in addition to the traditional initial cost.

2. ALIENATION

The alienation of the worker from society, from himself, from the political system, is widespread in the American society. Alienation is the feeling that the worker is in, but not a willing part of, the world in which he lives. He works to enjoy leisure and amenities. He rests to recover from the stress of unnecessarily dull work. We have moved in too many places past the criterion of "the work is good" to a situation in which "the work is terrible but the money's good." The traditional worker was so intimately a part of his work, that it was difficult to distinguish the leather from the leather worker, the clay from the potter, the iron work from the smith. Today, in contrast for many, work has become empty travail. Compared to the atrocious situations of the 19th-century factory system, with its fourteen-hour days, child labor, and dangerous practices, virtually every American worker today is well off. But that is not the appropriate comparison. The improved working conditions of American life coupled with education, prosperity, and leisure for reflection are raising new concerns and new standards of expectations. These new standards are not measured

against the conditions of battles long won, but against the humane potentialities of the future. Work is an instrumentality consuming large portions of the day, but focused only on providing rewards, such as bread, board, and recreation, almost totally disassociated from the work place. While alienation is not limited to the unskilled worker, it is clearest there. In any case, this ultimately creates alienation from the political system, one principal function of which is the governance of institutionalized work and its products.

A recent Gallup poll in response to the question "On the whole, would you say you are satisfied or dissatisfied with the work you do?" showed the following:

[In percent]

	Whites	Blacks
Satisfied	83	63
Dissatisfied	9	25
No opinion	8	12

Other data suggests that the Gallup survey may overestimate satisfaction. For example, the HEW survey on *Work in America* reports:

PERCENTAGES IN OCCUPATIONAL GROUPS WHO WOULD CHOOSE SIMILAR WORK AGAIN

Professional and lower white-collar occupations	Percent	Working-class occupations	Percent
Urban university professors	93	Skilled printers	52
Mathematicians	91	Paper workers	42
Physicists	89	Skilled autoworkers	41
Biologists	89	Skilled steelworkers	41
Chemists	86	Textile workers	31
Firm lawyers	85	Blue-collar workers, cross section	24
Lawyers	83	Unskilled steelworkers	21
Journalists (Washington correspondents)	82	Unskilled autoworkers	16
Church university professors	77		
Solo lawyers	75		
White-collar workers, cross section	43		

Professional workers who enjoy the highest levels of education, income, or autonomy, i.e., occupational flexibility, find the most satisfaction with work. The break seems to come with nonprofessional white-collar workers, where less than half would select again their occupational group. Least satisfied are the unskilled blue-collar workers. Of all the blue-collar workers surveyed, skilled and unskilled, less than half, with the exception of printers, would go back into that occupation. Should one choose not to interpret these data as revealing a problem, they at least suggest an opportunity for the improvement of American life.

Perhaps the situation is best grasped from S. Turkel's introduction of his book *Working*:

> This book, being about work, is, by its very nature, about violence—to the spirit as well as to the body. It is about ulcers as well as accidents, about shouting matches as well as fistfights, about nervous breakdowns as well as kicking the dog around. It is, above all (or beneath all) about daily humiliations. To survive the day is triumph enough for the walking wounded among the great many of us. . . .
>
> For the many, there is a hardly concealed discontent. The blue-collar blues is no more bitterly sung than the white-collar moan. "I'm a machine," says the spot-welder. "I'm caged," says the bank teller, and echoes the hotel clerk.

"I'm a mule," says the steelworker. "A monkey can do what I do," says the receptionist. "I'm less than a farm implement," says the migrant worker. "I'm an object," says the high-fashion model. Blue-collar and white call upon the identical phrase: "I'm a robot." "*There is nothing to talk about,*" the young accountant despairingly enunciates.

In countering or preventing alienation the reorganization of the work place will have to go beyond simple shifts within the factory. Major changes in work can go hand-in-hand with the long-term trend towards an information society and greater involvement of telecommunication in the economy.

I estimate that roughly 50 percent of the labor force is now in the business of generating, packaging, distributing, storing, interpreting, or in some other way manipulating data and information. This major structural change in the labor force is accompanied by the growth of telecommunications as the physical technology for this information-based society. Many fundamental organizational changes in the work place and the conditions for work are possible, if not likely, in these information-based, white-collar and professional occupations. For example, one possible long-term shift is to distribute work in such organizations as banks, insurance companies, government bureaucracies, and local government service agencies, to smaller, neighborhood work places.

Some white-collar, computer-assisted work could even be done in the home. Assuming, for the sake of discussion, that there are some long-term social benefits in this kind of restructuring of the work place, it is unlikely to come about simply from the operation of conventional economic forces, since there are major legal barriers to change. For example, should work in the home become, in any sense, commonplace, new tax legislation would be required to guide the kind of space available. Similarly, fair-employment opportunity programs would impact and interrelate to the re-distribution of the work place. Since many communities in the United States are economically, ethnically, or racially segregated, the distribution of work to neighborhoods might conflict with fair-employment objectives. Regulations governing health plans, occupational health and safety, and working conditions would undoubtedly retard or accelerate a shift to smaller work places. With any movement toward localized jobs, with the quick and convenient access to the home, one immediately has to consider the possibility of conjoint jobs shared by husband and wife. Assuming, for the moment, that these are socially desirable, it is clear that various kinds of institutional arrangements within corporations, with labor unions, and with government would have to be re-negotiated. To make these shifts realistic implies major government initiatives, first, in understanding the potential options; secondly, in probing their implications; and finally, in taking concerted measures to guide and promote the desirable and to discourage the undesirable.

Within the factory itself, the shift to reintegrate the blue-and-white-collar worker whether in terms of teams, job shifts, or a more interesting repertoire of tasks, suggests changes also in the nature of fundamental machine tools, the organization of the work place, and the work process. For example, should any substantial portion of the manufacturing economy move toward the use of robots, of the sort now entering the automobile plants, there will be some displacement of skilled and semi-skilled labor, and an increased need for computer-program-

mers and those skilled in maintenance and repair of this sophisticated equipment. This may be an opportunity to upgrade the factory workers, as well as an opportunity for exchange programs between the white-collar and blue-collar workers. There may be institutional obstacles to promoting these kind of innovations in the traditional union management relationships. Again, the tools of government, such as research, experimentation, information dissemination, and innovation in work in government service could play a large part in determining the ease with which this could be done and in the relaxation of the uncertainties associated with these changes. A minimum government role is the exploration of these potentialities and the determination of a systematic set of policy options for promoting the good and retarding the bad.

3. EXCESSIVE SIZE AND INTEGRATION

The high-growth industrial society absolutely required the scale of many enterprises to increase. This, in turn, has led to new ways of doing business and new modes of management. The conglomerate, for example, is a technique for maintaining an increasing scale of operations and profit growth. Within the framework of management of large corporations one sees, insofar as the thesis of John Kenneth Galbraith is correct, that the new mode of collegial management attends less to short-term profits or even long-term profits, but rather, seeks to stabilize its business environment on the supply and market side. Present shifts in the corporate environment reflecting changes in the resource and energy areas concerned with environment, present legislation dealing with health and safety, the changing characteristics of the consumer and the work force all imply change in management, and new strategies for organizing corporate affairs. So far, we have seen little response to the need for new modes of management in the corporate, labor, or government sector. Since each is increasingly bureaucratized, that tends to retard innovation unless the change is fully compatible with the existing bureaucratic structure. In the corporate sector, we appear to need new ways of organizing work, and new corporate strategies operating on decade to generation time-frames. In the labor sector we need to see the development of a view of labor and the life of the laboring man which breaks out of the conventionalized categories of the early labor unions and the Depression mentality. From government we need approaches which raise new questions, new options, new goals for society which government, in turn, can help to implement.

We know, for example, relatively little about the effects of size, location, alternative work arrangements on worker morale, productivity, and corporate decision-making or short- and long-term profitability. Perhaps government-inspired experiments could widen corporate management options or give labor a fresh perspective on its objective. One can see this conflict between the desirable social management and the inertia of large-scale institutions in the relationship of labor unions to reform in large cities. The unionization and bureaucratization of semi-professional workers such as school teachers stymie progress and entrench and protect undesirable structures, customs, and technologies. The identifying and managing of negative effects of large-scale industrial enterprises, such as chemical pollutants, or the promotion of

diversity in large-scale information enterprises, such as newspapers and television, are often stymied or extremely slow because of the arthritic struggle between resistant big business and fractionated bureaucratic government. This is not to deny that progress is being made, but only that that progress seems to come excessively slowly, at very high costs, and as the result of constant struggle.

An interesting example of the simultaneous growth of diversity and sameness is in information and news services. As news services become centralized through the press services and national magazines, it is in their interests to offer an increasingly technically excellent potpourri of information, appealing to a conventionalized diversity of interests. This growing sophistication in technique, touting a predictable diversity of materials, may drive out the more unconventional, local, ideological or special interests. The situation is roughly analogous to the way television has driven amateur sports off the scene while promoting superb professional sports. Television also killed amateur night and neighborhood entertainment while nationwide, first-class heavily marketed entertainment prospers. It is not at all clear that the shifts are in the national interests.

A major future role for the government will be in setting the constraints on the size of enterprises. The debureaucratizing of government service systems is one example of this. The reform of health services, the localization in smaller units of education institutions, the possible breakup of excessively large monopolies are further examples. The importance of integration and scale and the long-term implications of poorly conceived correctives, however, should promote comprehensive and systematic studies throughout government of alternative ways of handling these problems. For example, a commission with a three-year life to look at the restructuring of the telecommunication industry might be of great social value and would have strong long-term technological implications. Similarly, the study of the reconstruction of the Federal Communications Commission would be a narrower, but equivalently important task. In any consideration of measures to limit the size of integrated firms, a heavy investment in examining alternatives and means of transition is essential to avoid undue disruption. There are numerous other problems of the high-growth economy. Planned obsolescence, for example, is discussed below under raw materials, while consumption as a measure of success is considered under value.

B. *Price Structure of Energy*

In the last few years the economy has undergone what is widely thought to be a permanent increase in the relative price of energy. Aside from the question of whether this is intrinsically desirable, the fact remains that the shift has occurred. As a result, the relative cost of energy-intensive technologies has increased. There is a consequent demand for more energy-efficient systems. Striving to accommodate the fundamental shift in energy prices over the next several decades, therefore, will engender a massive reordering in technology. Some energy-intensive systems will be replaced by others less intensive. Other energy-intensive systems will be modified. Some energy-intensive functions may disappear. Readjusting to the permanent shift in

energy costs will be a major stimulant to invention and technological change.

C. *Awareness of Limitations on Raw Materials*

There has been evidence going back at least to the Paley Commission in the 1950s that the total domestic or worldwide repository of basic raw materials could not indefinitely sustain growth rates characteristic of the last several decades. A striking development in the last few years is the growing public awareness of the limitations of raw materials and the substantial shift within many sectors, such as copper and iron ore beneficiation to ores which were far substandard as recently as two decades ago. This growing awareness of the limitations of raw materials will have an effect quite similar to that of the fundamental shift of the price structure of energy, leading frequently to substitutions, extended product life, and so on.

One source of resource waste is formal planned obsolescence, which has become characteristic of many traditional industrial systems as a mechanism for stimulating high levels of manufacture. The high turnover is promoted by relatively low durability goods as well as by style and fashion-consciousness, especially in consumer goods. Planned obsolescence and high turnover-rate designs imply high cost for maintenance and repair since these items are not designed for ready maintenance or inexpensive repair. The cost and inconvenience of maintenance and repair stimulates high turnover, and it encourages more shoddy goods. This, in turn, stimulates corporate dependence on high-volume outputs. Closely related to planned obsolescence is the increase in disposable goods, such as paper cups, plastic containers, and throw-away beer cans. The resulting pattern of movement from mine to factory to shop to store to home to trash heap, which is only three or four decades old, is being severely challenged by structural changes in the cost of materials, and concerns about side effects of accumulating waste. It is undoubtedly the case that resource scarcities would induce more or less rapid shifts to more durable product designs and more easily maintained product designs. The adaptation of the appropriate technological substitutions may be relatively straightforward; in other cases, it may be quite complex.

The reordering of society to conserve resources and energy does not imply the elimination or reduction of material benefits. The necessary extension of product lifetime through an increase in the quality of materials, and more effective design for maintenance and repair could make more and better goods available to a wider, not a smaller, number of people. To the extent that planned obsolescence could be eliminated without increasing costs, buyers would get more for their money. In this connection a recent public survey shows that the public is less concerned with quantity than with quality and durability of goods. A movement toward a longer lasting, higher quality product in the marketplace would have further advantages of reduced transaction costs and less time spent by consumers to purchase and repair goods and to negotiate about deficiencies. As an incidental benefit, more free time would be available.

Substitution, which is the technological key to materials conservation, comes in many forms. It may involve materials, for example, substitution of aluminum for copper in electrical wire. It may involve

components, as the substitution of transistors for vacuum tubes. There may be functional substitutions, the replacement of beer cans or non-returnable bottles by returnable bottles. There are system substitutions, such as the partial replacement of the automobile by mass transit or the use of telephone instead of travel or heavier insulation of homes instead of increasing energy consumption. The first class of these substitutions is that most susceptible to the direct operation of market forces. The larger systems substitutions having the greatest effects across society are those least susceptible to the operation of short-term market forces, and yet, are the systems and substitutions most likely to have major effects on society. Substitutions will be a major stimulus to innovation. However, it is not clear whether undesirable negative multiplier effects from such changes due to displaced labor or lower-volume production may occur. Furthermore, it is not clear whether these shifts in design will occur in those areas that are of the greatest social significance in terms of resource conservation and other social needs. One of the roles for government is the explicit probing of substitution alternatives, and public policy measures for promoting some and encouraging others through laws, regulations, subsidies, research, information generation, incentives, sanctions, import quotas, and other tools of government.

D. *Societal Needs Outside the Market System*

There is a growing awareness, notably since the Great Depression and World War II, of the potential role of science and technology in improving the lives of our citizens in areas which, either by nature or historical accident, lie outside the market system. Traditionally, government activities include roads, dams, waterworks, and canals. More recently, they also encompass technological developments in health care, mental health, human rehabilitation, recreation, airports, and many other spheres. The first wave of the application of postwar science and technology to social needs has been completed and a number of more subtle applications and developments can be expected.

As it now stands, the overwhelming number of Americans have available to them cheap, plentiful food, clothing, shelter, and information. The next wave of technological advance will deal with the questions of improving the quality, diversity, and satisfaction in these consumer areas; and in meeting neglected needs, such as those of the handicapped, those suffering from unusual diseases, and the socially, the culturally isolated. As discussed below, technologies will be developed dealing more directly with man as an organism and with the social relations among people.

It has now become commonplace to recognize that many of the effects of technology which turn out to be important are outside the influence of the market process. Consequences not covered by the prices and costs of the sellers and buyers are referred to as externalities. In a parallel way, we are coming to be aware that many of the opportunities and needs for technology are also outside of the present market mechanism. An example of this is in pharmaceuticals, where industry is not motivated to invest tens of millions of dollars in searching for new drugs to combat certain uncommon diseases because of the small market for such drugs. Similarly, many major diseases, such as

schistosomiasis, a common disease in Asia, Africa, and South America which debilitates by blindness and tissue damage, and other vector-borne diseases of the tropical and sub-tropical world, have not attracted the interest of the pharmaceutical industry because the industry has focused on the more profitable and reliable markets of the industrial and advanced nations. To meet the needs of the developing nations, directly or through aid, a market would have to be created by government or the process would have to be carried forward by subsidization of research, so that on completion of the research cycle knowledge would be available to be exploited by the market. It is worth noting, as an incidental point, that with the decline in European colonialism, the interest in tropical medicine in the Western centers of medical research has virtually declined to zero. While malaria has been, and continues to be, a major public health disease, it was only under the stimuli of World War II and the Vietnamese war that the U.S. government initiated major episodic programs in malaria treatment.

Another example of technological opportunities outside the market system is that of wiring the nation for telecommunications or cable television to facilitate public feedback and participation in executive and legislative processes. This is not likely to come about by the operation of the market and requires the intervention of government.

E. *The Drift in Social Values*

Over the last several decades, mass education and communications have led to a highly educated population, and rapid technical progress has yielded prosperity and the expectation of continuing prosperity. Associated with these long-term trends is a measurable shift in a wide range of values held by Americans. The degree to which these are fundamental or permanent changes, or merely superficial responses to shifting circumstances is unclear. More immediately relevant to the problems of technology is that leisure reinforced by education and prosperity has led many to reflect on the quality of life, and to insist on further improvements in that quality. The permeation of society by middle-class values has produced a strong trend toward public participation in government and non-governmental decision processes. It is influencing decisions in all spheres. Changing social values are creating new demands and new constraints on technological developments within traditional areas. On the one hand, increased education is creating a population and an electorate which is eager and prepared to assimilate information and to deal in an informed way with its implications. The educated also more effectively impact on decision-making and politics. The participation movement itself is perhaps most clearly reflected in the environmental impact statement process, but it is occurring in hundreds of areas and elements of government at local, federal, and state levels.

Participation seems to have its clearest, most unequivocal values in local or regional issues, where the affected parties have direct and immediate knowledge of the situation and can perceive most effectively the implications of change. Public participation seems to be, at least by the present processes, less clearly applicable or less clearly socially effective in those issues which involve costs or inconvenience in

one location, but benefits delivered elsewhere, as, for example, in the siting of a utility, or the opening of a mine in one region to meet the economic needs of another region. We have not yet developed an effective cross-community participation and compensation mechanism. The participation process also seems to be somewhat less effective in dealing with issues that are more speculative, remote, diffuse, or nationwide. Examples of this sort may be recombinant DNA, military and strategic developments, international technological assistance, regional development policies, and technologies which operate on a national basis, such as transportation, telecommunications, and weather modification.

Values are shifting in other ways affecting technological options. Conspicuous consumption, which has been a prominent part of the industrial society, reflected in the acquisition of goods as a measure of social progress and personal success, may not be coming to an end, but it is changing. Conspicuous consumption can evolve into a pathological system in which emphasis on trappings and superficialities is increasingly at odds with the needs of individuals and their mature development. There are decreasing margins of satisfaction from the second home, the third car, the fourth TV, fifth radio, and the tenth magazine. As each technological development is assimilated, it forms a new baseline for expectations for more and better rather than a stable level of individual contentment.

Some of the shift to new conspicuous consumption involves personal services of a social, psychiatric, psychological, and educational sort. It is also manifesting itself in concern for higher quality, as for example, in the move toward stereo and quadraphonic music, and in greater diversity in such areas as hobbies and recreation. These trends are being promoted, and are consonant with the changes in the costs of energy and materials, and become one additional factor in promoting the technological changes associated with those price shifts.

F. *Government Intervention*

The expanding government roles in the economy since the Great Depression and World War II are neither accidental nor ideologically driven. It is rather a general worldwide phenomenon, particularly strong in the United States, responding to the complexities engendered by rapid growth and technical change, and increasing interdependence. Society has mandated government intervention also in the management of technology, for example, the SST, nuclear power, the new chemical substances screening processes, controls on biochemical research, etc. We must hope that the role of government will become more flexible, future-oriented, and sophisticated in these matters.

Government intervention may also find a socially critical role with regard to the export of American services, know-how, and products. There is a class of international aid and assistance objectives which are not particularly susceptible to the multi-national corporation mechanism of technology transfer. These deal with such basic things as crops, food, medical technology, education, and what have come to be called "appropriate technologies." These areas may present significant export opportunities for the United States. A crucial element in dealing with these opportunities outside the multi-national corporation framework is the mechanisms for identifying the needs and oppor-

tunities and the know-how that marry up to make exportable products. Government could help to identify these needs and to stimulate the associated enterprises.

As government increases and becomes more sophisticated in its intrusion into the techno-economic structure of society, one can anticipate that these interventions themselves will generate technical innovations in management, in information generation and handling, in public participation, and in decision-making. One can, for example, already see how 7,000 environmental impact statements has engendered an intellectual cottage industry. Government intervention in managing externalities such as pollution have created demand for technical innovations in physical control, as well as in management and data collection to monitor environmental changes.

Much of this paper is directed to highlighting these opportunities for governmental policy intervention. They are summarized in the last section o,f the paper.

G. *Maturation of the U.S. Socio-Economy*

It is widely argued with great credibility that the U.S. has passed through a major phase of industrialization and has moved into a so-called post-industrial society. The post-industrial society is characterized by a knowledge-driven economy and shifts in the production methods and output mix toward fabrication and services, which in turn, generate new demands on technology and new opportunities for economic growth. The movement toward a mature U.S. economy is part of the natural development of the society. The problem for government, industry, and the individual is to anticipate the implications of that change and to prepare for them through timely adaptations in public policy. The high degree of integration of the modern world leads to a need for social stability. That implies technological systems which are stable enough to permit well-ordered change. Adequate government policy requires preparation to develop better knowledge and understanding about the behavior of the technological system. Similarly, shifts in the price structure of energy and the increased public awareness of the limitations in the number of sources are further stimulants in the movement to a mature economy.

A mature post-industrial economy and society would emphasize conservation in materials and greater durability and efficiency in product design, greater prominence of knowledge and information enterprises, depending upon science for goods, services and knowledge to build social controls. This section will explore other aspects of the mature economy and their implications for technology, such as the social movement toward human fulfillment, i.e., the opportunity for each person to more closely approach his full range of potential developments. Economic maturity does not imply less of what we have, but rather, more, different, and better.

1. A MATURE SOCIETY IMPLIES MORE AND DIFFERENT, NOT LESS, TECHNOLOGY

The present dominance of physical technologies may move into relative decline to the advantage of biological and social technologies.

But physical technologies also may become absolutely more important in the future. A major area for continuing development is telecommunications. This is consonant with development of an information-service oriented society. Expansion of biological technologies, not only in the farm sector with improved plant genetics and biopesticides, but development of fundamental understanding of photosynthesis and its application in new ways, such as possible expansion into the energy plantation, can be anticipated with some confidence. The growth of biological technologies for man, the improvement of human genetics, the conscious design and development of improved quality of humans, the improved ability to maintain health both on an individual and on a public health basis are immediately ahead of us. Environmental technologies of earthquake control, hurricane moderation, rain making, and major civil works on land and in the oceans will become national and international opportunities.

A main arena for future development, however, is likely to be in the still uncertain and ill-defined areas of social technologies: The design of new approaches to social institutions and instruments to achieve social objectives.

One can anticipate for the future a rich burgeoning of technology, the early glimmers of which we are beginning to see. These technologies, however, do not necessarily imply more and bigger apparatus and organizations, but rather simpler and more personal ways of doing things. Perhaps, the one central characteristic for the technologies of the future is that described by Buckminster Fuller in the phrase "more with less." In its crudest form, better design at perhaps only small costs can give better, longer, cheaper service. Better automobile engines and smaller cars will use less fuel and will make more effective use of national and personal resources. In general, improved insulation and structural design in the built environment could conserve material and lead to functionally more effective structures.

2. MANKIND TO FULFILLMENT

Progress has been associated properly with measures of goods and income as the standards of growth. It has been quite correctly assumed that each person's lot will more or less improve with the acquisition of goods and income. Having reached a general level of prosperity there is now a new view coming forward that would focus more explicitly on the personal or internal development of the individual as a crucial element in the post-industrial or mature society. Personal aggrandizement, cultural fulfillment, close attention to interpersonal relations, and a more variegated, fulfilling set of social and institutional arrangements are various facets of this general sense of mankind to fulfillment. One term often used to imply the core of these personal changes is self-actualization, which could be interpreted as the opportunities for greater individual development, autonomy, and choice.

One can get suggestions of what self-actualization means when one considers the leisure world of the immigrants of the last century through the 1920's. Then, one or two weeks of rest in the country in a stylized vacation, away from the sweatshop and the factory, was considered the apex of leisure. Compare with that the next generation or two—a vacation with its numerous opportunities of travel, recreation, skiing, sight-seeing, scuba-diving, amateur archeology, and so on.

Compare that second phase of self-actualization with the opportunities of the future in terms of learning, meditation, experiences, and so on.

One finds it difficult to anticipate what that new society would be like. But one can sense that what may be in store is likely to be profoundly different. The newly emerging psychological technologies of bio-feedback, meditation, conditioning and others will go far toward relieving human distress and opening up new vistas of internal personal improvement. Similarly, the social technologies of group interaction, conflict resolution, information transfer, and judgment explication will better relate man to his institutional and governmental environment. These relatively unconventional technologies are technologies by virtue of being examples of the conscious use of human arts or sciences for the accomplishment of human goals. It is this definition which makes electric light bulbs, hybrid corn, and the invention of income tax each an example of technology.

The potential opening up and ventilation of government implied by these technologies may stimulate democratic processes and make public participation more effective and practical. To a substantial degree the negatives associated with the mature society (incorrectly labeled a no-growth society) flow out of our natural ability to anticipate the negative with apprehension and our inability to anticipate the joys of new concepts and breakthroughs in the overall quality of life.

Likely to become increasingly important in the future are some good and bad technologies which directly affect people as organisms, such as:

Recreational drugs.
Genetic manipulation.
Biofeedback.
Meditation.
Organ transplantation.
Bioengineering for handicapped.
I. Q. and aptitude tests.
Behavior modification.
Individualized teaching.
Genetic and social counseling.
Man/machine extensions.
Sex selection.
Radical cosmetics.
Mind-changing techniques.
Torture.

3. MORE WITH LESS

Taking Buckminster Fuller's concept of "more with less" one can fantasize along the incorrect axis of less of what we now have and trace out dark and depressing versions of the future. The more likely and more positive element of more with less is a world which is substantially different from the present. Consider, for instance, the possibility of thirty percent of all work being done at home. The implications of that for savings in fuel, in transportation, in automobiles, the implications for more highly integrated households, more intimate opportunities for cooperation within the family and with neighbors, and local social groups, the greater availability of discretionary time for personal development—imply a qualitative difference not just a

quantitative change. These potentials for qualitative reorganization mark the major transformation in society ahead of us. The possibility of cooperative team work for husband and wife has major possibilities for a world substantially different from today's centrifugal family life, with home as a domestic service station. The historical, cooperative, stable life of rural America may be revived in urban America, as joint work, gender equality, and local work places draw the family together.

It should be clear that such radical changes in the structure of work in society are so poorly understood as to make it difficult to even identify what principal benefits and shortcomings of such a new society might be. The crucial role for government now is the elaboration, the probing, the study of the policy implications of these kinds of options.

It is important to emphasize that the plain, naked concept of no growth, the shutting down of economic machinery of American society, could quickly lead us into degenerative decline. But the opportunity facing us is not to shut off that machinery, but rather to transform it steadily and consciously into machinery working toward fulfillment of ourselves and our society. It cannot come about spontaneously.

The social forces discussed above are not in themselves sufficient to explain or forecast the course of technological change over the next three to five decades. The central characteristics of technology itself in our society may, in some sense, set independent constraints on or open opportunities for future development. These factors are considered in the next section dealing with technology itself.

III. Basic Propositions About Technology

Technology itself is a crucial factor in shaping future technologies. The particular ways it is institutionalized and its degree of complexity have their own imperatives. The fact that basic science now leads technological applications in many fields (rather than trailing, as often in the past) opens a new bounty of potential benefits and risks for the future. The undesirable side effects of technology drive toward new countermeasures and alternative technologies. Some aspects of technology that will influence future development are discussed next.

A. *Technology Has Created a Man-Made World*

Modern Americans live in a man-made world. We know very little about the stability and resilience of this complex social structure. But there are numerous suggestions of serious risks associated with this new world: dam collapses, nuclear energy misuse, thalidomide, kepone in the Chesapeake Bay, misuse of diethylstilbesterol, vinyl chloride, and asbestos. These vulnerabilities have one clear implication for government: There is a need for closer and earlier attention to the stability and the weakness of technological systems. Existing systems must be probed and strengthened. New systems such as electronic banking and unconventional energy should be examined promptly and designed to minimize vulnerability. Stability should become a key goal in the future social management of technology since the technological complexity of society and its national integration leave it vulnerable to catastrophic collapse through economic, technical, or social breakdown.

B. *The Complexity of the American Technological System Is Unique*

Technology is at work in every society. What is unique about technology in the United States is its large scale; its interrelatedness; its pervasiveness in life and the economy; the incredibly large dollar investments; the rapid rate of turnover; the degree of integration; and its universal and rapid impacts on every aspect of our lives. Highly integrated industrial sectors, such as motor vehicles, telephone, television, or petroleum, provide both a ready market and a stimulus for a new technological development. These systems are so large that their needs automatically create a massive market, and this provides a profound stimulus for research, development, invention, and innovation within the company. On the other hand, any external development which will improve the system is likely to be adopted. The big systems have the resources, drive, and potential to define and meet their needs internally or by stimulating and assimilating external R. & D.

This regenerative system of invention focuses on and makes it possible for one technology to survive at the expense of other technological alternatives. The development of petrochemicals shut off interest in coal or forest chemicals. Consequently, some kinds of changes necessary in that massive integrated system may be very hard to bring about.

In general, the role falling to government in connection with an integrated socio-economy centers around the need to understand better how that system operates as well as how it could operate in competition or cooperation with alternatives technological subsystems.

C. *All Major Societal Problems Have a Technological Origin*

Many people believe that there is no major problem in our society which is not either directly or indirectly a consequence of the developments of science and technology.

Unfortunately, most of the more serious problems stemming from technology do not arise immediately: they rather tend to build slowly, to converge with other effects, and not to be clearly associated with any particular action, event, or decision; i.e., they are externalities.

This proposition on the technological origins of social problems is not intended to suggest that other social, economic, cultural, institutional factors are unimportant. It only points out that technology is a basement consideration. As an historical example, the development of mechanical harvesting of cotton created a mass displacement of black farm workers. Personal need to resolve issues of joblessness and restricted opportunity caused emigration and the associated immigration to the northern cities. The creation of a new social problem was a result remote in a time and place from the interests and the reasonable and desirable social and personal goals of more, better, and cheaper cotton. The free play of self-interest with too poor public understanding of the future societal implications of mechanization led to this unfortunate situation. Roughly the same phenomenon is holding now with regard to Puerto Ricans, Mexicans, and Appalachians and other internal underclasses in America.

A growing awareness of the importance of external diseconomies and the widespread feeling that many of them are avoidable is leading to modifications to correct old problems and prevent new ones, for example, the emission control devices on automobiles and the air and water pollution controls in industry. These controls themselves stimulate growth and have the overall effect of improving society.

D. *The Capabilities of Technology Are Limitless*

With regard to future technological developments, there is no goal which we cannot effectively work toward. This is true at least in the minimal sense of beginning to systematically explore rational movements toward manipulating, controlling, and managing our affairs to make any goal ever increasingly likely. The only ultimate constraints are logical contradictions and violations of fundamental physical laws. Our Promethean capabilities apply not only to day-to-day goods, products, and services, but also to the grandiose: the management of the planet, continental engineering, revamping of the surface of the earth, the oceans, the ice caps, and the atmosphere.

This truly new capability to move in virtually any direction creates a new problem. Until recently, ideas and opportunities were limited by capabilities. Now it is resources which limit ideas, opportunities, and capabilities. While we can do anything, we cannot do everything. Learning to define, orchestrate, and guide these new societal choices is a major unfolding task for government. The social direction of science, technology, engineering, and their applications will have to become more sophisticated, flexible, and use-oriented.

E. *There Are Social, Psychological, and Intellectual Technologies*

While the limitation of physical technologies have by no means been reached, there are more new opportunities in biological, psychological, intellectual, and social technologies which have been relatively little explored. These may come to be the new dominant element over the next half-dozen decades. A true technology of man, not just of his artifacts, seems to be immediately ahead of us.

Recognizing that social technologies exist is important on three grounds. They are increasingly significant for society. Secondly, many of the analytical and research techniques appropriate for physical technologies can be fruitfully applied in this area. Finally, the social technologies comprise the major mechanisms for social control.

The following list includes some areas in which new social technologies might be applied:

Work arrangements.
Institutional rewards and motivation.
Family life.
Care of needy, handicapped, poor, elderly.
Health care delivery.
Forecasting.
Crime prediction and prevention.
International currency.
Boundaries of countries.
International peacekeeping.

One-stop government services.
Constitutional reform.
21st-century Bill of Rights.
Recreation.
Education in maturity.

F. *Three Techno-Economic Planning Criteria Dominate Decision-Making*

Three and only three basic techno-economic planning criteria enter into the decision to open a hand laundry or a McDonald's quick food stand, to build Grand Coolee Dam or the Alaskan pipeline, construct a water works or a public health program, or market a new camera or a new car. The same three principles drive every socio-economic enterprise in America. These criteria are:

Can you build it?
Will somebody pay the bill?
Is it safe?

When one considers all the trouble now manifest in every sector, whether it is crime in the streets, urban congestion, alienation of workers, disruption of family, the movement of minority groups into the new jobs, occupations and home sites, whether it is a question of environmental pollution, international trade, or war and peace, every one of these questions have become a major national issue because of side-effects of technology. But factors outside of these three techno-economic planning criteria, factors not entering into the chain of buyers and sellers, now seem to be dominant in creating our problems. It is not that these criteria are faulty. In our complex society the planned, slow-building side-effects frequently become the critical or dominant ones. Therefore, the traditional planning criteria should be enlarged, not displaced.

G. *There Are Three Stages of Technological Evolution*

A major new technological invention generally, if not always, passes through three stages. The first stage is that of substitution for a previous function or activity. So for example, the introduction of office machines substituted for or augmented activities performed by human labor. In the second stage, one finds the reaction to the substitutions. The institution or the system in which the technology is embedded begins consciously to evolve and change to better utilize the new technological capability. For example, one finds billing procedures, office forms, data flow and the structure of the information within the corporation changing to better utilize the new office technology. Finally, one reaches the point where the new technological gadgets have permeated the institution or the society, as the case may be, to the extent where one begins to find new and undreamed-of uses for the technology. The essential condition for that stage is that the technology be pervasive and so cheap that new things can be effectively tried. This stage is marked by the most general and complex societal impacts.

The first two stages are dominated by market considerations. But the third wave and the most important impacts are usually remote from the thinking of those dealing with the first two phases.

The stages in this evolution, while generally clear, often involve numerous small minor changes and multiple technologies resulting in numerous small waves of the three-fold cycle before the major pattern of effects of the full three-fold cycle are clear.

In part, the waves of change engendered by the substitutions occur because technological changes are neither continuous nor fungible. The replacement of paper by plastic bags, the displacement of home cooking by canned and then frozen food, the replacement of the horse by the automobile are not simple substitutions. While no major technology represents a simple, single, straightforward, tidy substitution, technology is almost always offered on the basis of the short-term improvement in products or processes, i.e., offered on its substitutability. Closely related to this is the general behavior which suggests that technology is viewed as if it were continuous, whereas, at some point almost every technology involves discontinuities. The most interesting recent example of this is the requirement for continual improvement in the quality of automobile exhausts, applying pressure to the industry as if the necessary changes were in a continuing smooth relationship to pressure. But a half dozen analyses rather unequivocally make the case that major discontinuities of technologies are implied in meeting those standards. Continuous pressure cannot always yield continuous change. Knowing when it can and cannot is a crucial need of government. The social implication of those discontinuities can be enormous to society and the economy.

II. *Technological Generations Compete*

The concept of a technological generation is helpful in understanding technological change. For example, the first airplanes represent first-generation technology. The next wave of new, improved planes are the second generation technology, and so forth. In general, in the early development of a new major technology there are substantial improvements with each successive generation. However, in order to hold onto continuing economic profits from improvements and new technology, those gains often become perverted to cosmetic style shifts, appeals to conspicuous consumption, and appeals which are intrinsically resource wasting.

There are inter-generational conflicts between established and competing new technologies. Enthusiasts advocating a new invention, technology, or social strategy often pit overly optimistic hopes for the new against the proven old technology which has a high degree of reliability or efficiency. One lesson out of this inter-generational conflict is neither pessimism nor rejection of the new but the need for caution and forcefully investigating the applications and the consequences of the major technological alternative.

The second lesson is that a new device in its early generation is usually competing against an established technology, established markets, established customs, and established economic interests. These are all roadblocks to change.

The third lesson is that experience in testing and use cannot be hurried beyond a certain critical pace without severe risk that they will be badly done. Consequently, first generation technologies and gadgets are often at a serious disadvantage with established technologies. One of the roles for government here is to be sure that the

early generations have a fair competition with their more established forebears. Without appropriate government intervention to assure fair testing new technologies may be stultified or smothered before their promise is proven.

I. *Science Is Beginning To Lead Technology*

Traditionally, technology and technical problems spawned and stimulated science. In the past few decades, this relationship has been reversing. Electronics and genetics are conspicuous examples of science preceding and becoming a prolific wellspring of new technologies.

Lasers, holography, other developments in optics have vast potential for impacting on communications. Developments in low-temperature physics (cryogenics) are only just beginning to move into areas of application. Biological developments in understanding the nervous system and the electrical and biochemical bases of behavior and growth offer boundless opportunities. Fundamental developments in mathematics coupled with new theories of control, feedback, and cybernation will undoubtedly have practical applications in building more stable technological systems. Knowledge in geology is likely to affect our technologies of minerals, waste disposal, energy sources, food, and natural disasters.

The opportunities from science are perhaps greater than from anywhere else over the next several decades and hold at least two implications for government policy. The first involves a need to identify goals for the development of basic knowledge in areas of major social concern.

Traditionally, science perceived its task as one of disclosing fundamental knowledge about the structure of nature. It was largely a privately funded activity and a relatively small part of the economy at any time or place. As the scientific apparatus has grown to be an institutionalized part of public policy, fundamental questions arise about the direction of this powerful machinery to more public-directed goals. Assuming some goal-setting is appropriate the second and even more difficult question is choosing the means of intervention and direction.

As it stands now, virtually no basic research program of government in the civilian sector has delivered significant technological benefits to deal with education, welfare, crime, justice, public safety, peacekeeping, bureaucracy, etc. A fundamental need, therefore, is the stimulation of basic research on our social problems.

The prepositions about technology and the social factors discussed earlier are among the dominant influences in our technological future. The next section draws together some implications for government from this complex situation.

IV. Some Implications for Government

Some principles useful in defining more specific policy implications for technology and economic growth:

> Future policy with regard to technology should be premised on the need to anticipate the depth and diversity of the consequences of technology; to maintain flexibility in implementation; to provide feedback mechanisms to generate information useful for

public and private decision-making. Lack of knowledge about impacts, alternative technologies and related policies is a principal limitation on present decision-making.

Major changes in American society come in different sectors at different rates. Fifteen to thirty years usually are needed to bring about major changes. Attempts to achieve them in shorter intervals are likely to be unrealistic or wasteful of resources. Currently, automobiles, highways, buildings, power plants, and dams have expected lifetimes of ten, twenty, forty, fifty, and a hundred or more years, respectively. Change must take these lifetimes into account.

Uncertainty promotes conservatism, risk avoidance, and conventional choices. Consequently, a major role for government is to structure and manage uncertainty, to activate market forces to explore and develop new technologies, and to give specific focus to desirable public projects.

Bureaucracy is a major element in public and private institutions. Its usual risk avoidance and conservatism should be compensated for by specific programs encouraging risk and emphasizing accomplishments, rather than fear of sanctions.

A better match between the techno-economic problems in our society and the division of public authority is essential to the social management of technology. No major problem area is the responsibility of a single or even a few units of government. Consequently, every problem and opportunity is likely to be caught up in conflicting, paralyzing pressures. Examples are in the areas of energy, pollution, traffic, housing, and health.

The three traditional technical economic planning criteria of feasibility, marketability, and safety in the public and private sectors must be enlarged to include new considerations of wider scope and deeper penetration into the future. These criteria, for example, should deal with effects on mental health, family stability, the environment, law, crime, international affairs, business, and cultural patterns.

Market forces, while powerful, are not likely by themselves to deal effectively with technological consequences outside the market system, or with long-range social objectives of education, foreign assistance, or social welfare services; major technologies not part of the market system; or public service, human rehabilitation, and mental illness, and unprofitable needs, e.g., rare diseases.

Major sectors of the economy have not embraced research as a key element of their corporate or industrial strategy. Doing so would have a large pay-off. Ten companies account for 29 percent, and twenty companies for 40 percent of all industrial R & D. More R & D effort could undoubtedly help the construction industry, mining, fisheries, forest products, shipping, ground transportation, food preparation and delivery, textiles, appliances, and retailing.

The principal implications for government in regard to technology and economic growth discussed below fall into four major areas:

The management of risk and uncertainty in order to promote useful techno-economic change.

The generation, distribution, and use of knowledge, especially knowledge for policy planning and programs.

The institutionalization of technology and its regulatory and control institutions.

The support of research and development. While this is a subset of the knowledge area, it is sufficiently important to merit independent note.

A. *The Principal Role of Government in Relation to Technology*

The central role of government in the future development of technology is in the management of uncertainty. One important way in which this may be achieved is through setting stable, effective conditions on market operations to encourage powerful market forces to develop needed technologies. Other ways are through research, by the production of information for public, private, and personal decision-making, by the skillful orchestration of the instruments of government for flexible future-oriented-feedback-engendering policies and programs. Government must enrich, not foreclose, our options.

The attempt to seek too rapid shifts in time of crisis, on the one hand, and the unwillingness to carry out gradual, systematic change on the other, are the Scylla and Charybdis of government intervention. The tendency to over-specify rather than permit the operation of normal economic forces to prevail under general constraints, and the tendency not to be flexible enough in legislation, not to build in feedback, and to create, therefore, a rigid rather than an organismic policy toward necessary change are other shoals on which public policy may founder.

As an example of reducing or otherwise managing uncertainty, consider solar energy: It may be that a necessary condition for the wider use of solar energy technologies will be the provision of tax incentives, government research funds, indemnification programs, changes in Federal housing regulations, new rules of ownership, and so on. The identification of an appropriate social goal and the resetting of the constraints to meet that is a major conceptual challenge to government. Perhaps the single most potent tool for examining these complex situations is the concept of technology assessment. But more on that below.

As an illustration of an energy area in which present uncertainties may act as an unnecessary crippling constraint on the development of a future resource, consider geothermal energy. There are three kinds of uncertainties of such importance to the industry that they may delay adoption of the technology.

The first is whether geothermal resources are to be treated as mineral resources or as water resources, or *sui generis*. Either of the first two options carries an encumbrance of legislation, regulation, etc., which was not designed for and did not even consider geothermal resources. These present severe impediments to the development of geothermal resources.

The second kind of constraint is a lack of knowledge on how to estimate the energy content of the field. This, in turn, creates uncertainty on optimal plant size and design, and hence, influences questions of return on investment and reliability of future supply.

A third uncertainty has to do with the optimal rate of enery withdrawal from a geothermal source in the absence of adequate experimentally grounded information. The utility would run the risk of underwithdrawing and hence, not utilizing its investment to the

optimal extent; or perhaps worse, overwithdrawing and finding itself, so to speak, high and dry at some future time. The management of these kinds of intrinsic uncertainties is essential to the growth of this new technical opportunity.

With regard to setting stable conditions for enterprise, a major consideration should be the establishment of conditions which avoid carrying large numbers of issues into the courts. The movement of issues into the courts generally involves mechanisms which are not democratic, which are not subject to broad public discussion, and which do not necessarily act in the best short- or long-term interests of the nation. Court procedures often only embalm defective law.

1. APPROPRIATE TECHNOLOGIES

An interesting mixed use of advanced and mundane technology leading to vigorous growth is in the area termed "appropriate technology." Freed of its ideological overtones it is the design and employment of technological elements and systems more appropriately scaled to maximize the long-term social return. Insofar as appropriate technology is one strategy in response to energy and material price shifts, as well as to externalities of scale, it may modify the size, kind, and distribution of devices.

For instance, the employment of solar electric technology on a decentralized basis at many sites will not necessarily imply advanced technology although it will imply the growth of new kinds of applications. Similarly, feeding surplus electric power generated on-site back into the electric grid may not involve high technology, but it may involve substantial technological changes.

One role for government in managing uncertainty here is to define goals in operational ways. Furthermore, it should encourage competition between strictly technical solutions and social and market solutions.

B. *The Need for Knowledge for Policy Purposes*

Within the framework of technological and scientific decision-making in government, the principal limitation is the inadequacy or absence of knowledge organized for the purpose of an informed public policy. Most information is collected for other purposes. A major improvement in executive branch information gathering would be the explicit identification of the information needs for technological and scientific policy both in and out of government.

The principal knowledge needs for policy-making in and out of government, and for those influencing decision-making are encapsulated in the concept of technology assessment. Technology assessment is the name for a class of policy studies which attempt to look at the widest possible range of implications of a new technology, or the extension of an old technology in new ways. Included in that study would be anticipation of impacts on social, environmental, economic, and political aspects of society, and in the analysis of public policy options, alternatives, and consequences for managing that technology.

A substantial number of technology assessments have been conducted. They have demonstrated their value for public policy. Consequently, this approach, if vigorously propagated through the public

and private sector, would raise the understanding of technological issues to a new, higher level. Technology assessment could serve the purpose of widening public choices and assist in opening the bureaucracy and the decision-making process to fresh ideas.

The complement to setting constraints which are likely to avoid litigation is to extend and expand the application of technology assessment to regulations, legislation, and other government procedures which set long-term processes in motion. This would be a major breakthrough in the effective management of technology for the commonweal.

The integration of the economy reflected in the nearly total networking in all sectors tends to negate the basic principles of traditional Adam Smith economics. Smith economics has as basics: (1) Large numbers of buyers and sellers, none of whom is large enough to have a commanding effect on the market, and (2) full knowledge flowing among the buyers and sellers themselves. This second condition is very difficult to meet today. One role of government, therefore, is that of dealing in new ways with these non-traditional markets. Another role of government where a clear impact could be made is in addressing the information needs of buyers. Information in a form and timeliness that is useful for personal and institutional decision-making is of growing urgency.

C. *The Institutionalization of Technology and Its Regulatory and Control Institutions*

Many technologies are not likely to develop adequately unless they are set in a proper institutional context. Among these are: Weather modification, earthquake control, hurricane mitigation, telecommunications in both sparsely and densely populated areas, and health care delivery. In the energy area alone there are numerous needs for new institutions, such as in geothermal energy. A crucial policy problem is to identify the significant options which will simultaneously meet public needs, stimulate innovation and accelerate changes, and where suitable, promote the operation of market forces.

Subsidiary to institutionalization are major questions of equity associated with new public technologies such as earthquake control and hurricane modification. The primary role of government is the identification of the equity issues and institutionalization of the mechanism for dealing with them. For example, one can anticipate that within a decade there will be a capability to mitigate earthquakes. If this involves cutting a potential for an earthquake of Richter level 8.5 to an acceptable level through the continuous activation of earthquakes at Richter level 3.0, this would imply a virtually steady day-to-day operation of low-level earthquakes. The implications and associated equity questions are currently totally outside public policy. Hence, the technological developments of these socially beneficial technologies may be precluded.

1. RESTRUCTURING THE REGULATORY APPARATUS

Regulation of some sort is essential to the operation of complex systems. Yet most major regulatory agencies of government were set up decades ago in response to problems which are no longer of primary

importance. The internal evolution of the regulatory agencies to remain current is of mixed and questionable success. Consequently, a systematic approach to the restructuring and reorganization of the regulatory apparatus may be in order. Primary candidates would include those dealing most directly with technologies which have drastically changed. These include the Federal Communications Commission and the Food and Drug Administration. For example, revamping of the regulation of telecommunications would give needed new structure to government policy. Since the generation and deployment of knowledge is at the heart of our society and economy, effective regulation of telecommunication is a pressing concern. Parallel studies are in order with regard to other regulated sectors such as energy, banking securities, marine, and oceanographic affairs, health care, and transportation. Included should be the serious study of the future state of society, the identification of several different regulatory strategies and the full analysis of the implications of those alternatives.

2. DEALING WITH FUNDAMENTAL NEW TECHNOLOGIES

Fundamental new technologies such as weather modification, earthquake prediction and control, ocean engineering, construction of artificial islands, harnessing of tidal power, and deriving energy from wind on a large scale, open far-reaching new possibilities. Insofar as these capabilities have significant potential implications for the economy, government is faced with new sets of issues that will require new kinds of choices. These may include questions of whether the technology should be permitted, encouraged or prohibited from development on either a public or private basis. If the decision is to encourage market forces, then the policy questions involve the kinds of intervention which should be made, i.e., a decision among subsidies, regulations, incentives, prohibitions, etc.

The third class of policy issues is that involving equity or fairness; for example, if earthquake control technology develops, there may be sudden large shifts in land values or selective losses of property. What should happen if good judgment suggests that there should be modifications in control of flood plains? What are the equity issues in discouraging population movement into and promoting movement from these areas? And then finally, there must be mechanisms to deal with these problems. Obviously, two of the main things to be avoided in such mechanisms are: (1) costs which approach or exceed the fairness claims under consideration, and (2) mechanisms which become so highly procedural and stylized as to thwart rather than promote equity. The number of areas in which these questions rise is not limited to the physical examples above.

Health technologies such as therapies for sexual dysfunctions, genetic manipulation and bioengineering present similar issues and demands on government. Even traditional areas such as mass transportation and housing technologies (e.g., directed at energy conservation or new materials) present parallel issues.

In general, where the new technology is not compatible with the existing market system, or where it implies major public initiatives, it behooves government to attempt to limit and manage the uncertainties.

Government has provided the market for space exploration and it must almost certainly provide a market for weather modification, although most weather modifications now conducted are private efforts in rainmaking and hail surpression. But when we move to major programs of hurricane, cyclone, or typhoon manipulation, government must provide the market and the control for such techniques.

D. *Making Research an Effective Tool of Government*

Vast areas of government have not yet come to enjoy the benefits of research and policy studies as an aid to internal management or in the development and execution of their programs. Consequently, it would be useful where federal agencies which do not have significant research functions to specify a list of major issues confronting that agency over the next 25 or 30 years. Further specification of the applications they are making of science, technology, and policy research in addressing each issue would further sharpen planning.

For those agencies with substantial commitments to research, a series of questions probing the identification of issues the agency is facing, the general and policy research undertaken to relate to those issues, and specific means for organizing, presenting, displaying, and delivering general research and policy research results to users would be in order.

1. SOCIAL ACCOUNTING

Subsidiary to the development of policy information is the pressing need to modify the social accounting systems to augment and complement the current economic accounting systems. With regard to economic accounts explicit attention to the accommodation of externalities is appropriate to deal with social costs. Other kinds of accounting systems dealing with energy balances, quality of life, attitudes, aspirations, goals and satisfactions would be useful. Such data could profoundly inform economic and technology policy if collected and analyzed in an appropriate way.

2. LARGE-SCALE SOCIAL OPPORTUNITIES

The identification of large-scale social opportunities, and needs now outside the market system, could have major payoff for the nation. Among these are: major civil works, the wiring of rural and of urban America for telecommunications, the introduction of energy alternative systems such as solar or geothermal, seabed technologies, artificial islands and so on. Within the social sphere, major opportunities for reformulating public education, the distribution of welfare, the restructuring of cities and other habitats present various large social opportunities for technology.

3. R. & D. OBJECTIVES

Research and Development (R&D) are so crucial to the future of America and to technological change that they must play a key role in public policy. Some overall social objectives of R&D should include:

The generation of knowledge basic to the understanding of current and unfolding societal issues. This implies a modification

in the nature of basic research, which largely and historically flowed from science itself and its internal logic or from the pursuit of major military or ad hoc initiatives such as the space program.

The development of research and the socio-technologies as effective tools for an early warning about regional, national, social and international risks, hazards, and disasters.

The extension of research and technology into areas of social problems and the encouragement of applied social sciences.

The simultaneous interrelationship and comparison among and between traditional technological and non-technological, and social technological strategies and solutions.

The application of R&D to international problems and issues.

The application of R&D to foreign assistance and foreign trade.

The clarification of the intergenerational competition between established technologies and potentially significant new technologies. The latter almost of necessity cannot effectively compete because they are not mature enough to compete in either a market or a non-market system.

The application of research to large scale social experimentation. New mechanisms for major public programs have in the past too often been based on unnecessarily slim evidence. The extension of the concept of the social-experiment as embodied in educational vouchers and income maintenance experiments to other public policy questions could be a major boon to society.

The identification of systems vulnerabilities in oil, gas, communications, urban structures, etc. with a view to their better management, improved design and contingency planning.

Learning to promote entrepreneurship and the willingness to take risks whether as an owner, a corporate manager, or a government bureaucrat.

Specific indepth studies of alternative future worlds, for example, working out in greater detail the implication of 10, 20, 30, 50 percent less energy and materials per capita are urgently needed. These scenarios would become a public and private planning guide and public information base.

Stimulating the market in new and non-traditional ways.

The utilization of new and old R&D results by government and business.

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